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INTRODUCTION

Among the reasons why the attribute of intensity has not received the consideration in experimental investigations which has been given to other attributes of auditory perception, are especially the technical difficulty in controlling the intensity of tones and the lack of a convenient standard of tone intensity. There is no standard of tone intensity which is as available in psychological laboratories, as is the candle power for light intensity. Besides these, further difficulties appear in producing pure tones, in varying the intensity in a measurable manner and in maintaining a constant intensity.

The first step in this investigation was the construction of an apparatus by which the intensity of the tones to be used can be controlled.

The physicists who are best prepared to design the apparatus are not interested in the problem of tone intensity as it presents itself to the psychologist and for this reason it was found necessary to design and construct the apparatus in the psychological laboratory.

The problem was suggested to the writer while a student assistant in the laboratory, by Professor M. F. Meyer in 1909. The writer takes this occasion to acknowledge the great help he has received from Dr. Meyer throughout the entire time that he was working on the experiment,—assistance and encouragement which extended to every phase of the problem—mechanical, theoretical and practical. Because of Professor Meyer's wide experience with auditory phenomena in general and because of the fact that he had already started the problem, the writer was able to go ahead in a more direct path than would have been possible had it been necessary for him to work independently.

The apparatus difficulties passed through four relatively distinct stages, which will be considered in some detail in the description of the preliminary apparatus. It is considered worth while to describe these preliminary experiments so that others who may take up the problem of tone intensity apparatus may be spared some of the difficulties which were encountered.

It was continually borne in mind that tone intensity relations are an important part in nearly every investigation in audition. This is one reason why the apparatus has become so complicated. The following are some problems in which tone intensity plays a role. It also represents a provisional program of experimental work which it is hoped may some time be completed by the use of this apparatus.

Influence of phase on the intensity of tones.

Relative intensity of difference and combinational tones.

Relation between vocality and intensity.

Relation between tonality and intensity.

Effect of intensity on the consonance or dissonance of intervals.

Effect of intensity upon the apparent pitch.

Effect of intensity on pitch discrimination.

Limen for intensities.

Effect of intensity on the analysis and synthesis of tones.

Experiments in audition are more discontinuous than they are in vision. It is not likely that we will soon have pure tones which can be made very loud, and whose vibration rates can be made to vary quickly between the limits of audition, in the same way that brightness or saturation is now varied in vision. For this reason the usual experiment in tones will be restricted to relatively few tones or intervals.

The whole tonal scale must be worked over gradually but as the technique develops and the body of facts is extended much more satisfactory work can be done on the various theories of audition. Most of the current theories on audition were built upon considerations which were mainly qualitative in character. A theory, however, is of greatest use when it aids in also predicting quantitative relations.

The apparatus also lends itself well to experiments in vision in which it is necessary to have a constant illumination. The alternating current which passes through the sockets 36, fig. 4, is about as constant an electrical current as can be produced. With the proper Mazda lamp the apparatus will furnish an unvarying light up to about 100 candle power. Where vision and audition are to be combined in an experiment this fact is of especial importance.

I. PURPOSE AND SCOPE OF THE APPARATUS

The apparatus was designed:

1. To produce a number of pure tones.
2. To control the tone intensity.
3. To control the phase relations.

1. The test for a pure tone was the unitary character of the auditory impression. A tone was judged to be pure when a careful and attentive analysis by the unaided ear did not reveal overtones or upper harmonics of the forks or resonators. As a part of the apparatus consisted of the carefully tuned resonators 150, 200, 250, 300, 350, 400, 450, any tones having these periods could be readily detected, if present as overtones or asymmetry[1] tones. The extent to which an objective search for overtones was made was limited to these resonators. Disturbing tones and noises that were present to the ear were localized with a short piece of rubber tubing, one end of which was held to the ear while the different parts of the apparatus were explored with the other end. Such tones were usually caused by loose washers, the millimeter scales rattling against the resonators, etc. When once located they were usually easy to eliminate.

2. To make judgments of intensity, it is necessary that the tones can be started and stopped without any pronounced variation in the character of the tone at the beginning and end. A fork always changes its character when suddenly stopped and several seconds are required before an electrically driven fork reaches its constant amplitude. For this reason the forks were kept vibrating all the time and the tone generated in the resonator was the one started and stopped by a felt covered shutter. If the resonator is carefully tuned and properly adjusted over the fork, the tones "just slide in and out" quickly but with neither the beginning nor the end specifically marked.

[1] F. Lindig, Ann. d. Phys. vol., 11, p. 31 ff. 1903. Ueber Asymmetrietoene. M. F. Meyer, ibid, vol. 12, p. 889. 1904. Ueber Kombinations- und Asymmetrietoene.

The intensity of the tones was controlled by shifting the resonators to different distances from the forks. The mechanical details will be described in the Method of Experimentation.

3. By phase control is meant our being able to determine how the sound waves reach the ear relative to each other. This is of considerable theoretical importance because the character of the resulting sound wave, when a number of tones are sounding at the same time, depends very much upon the phase relations.

1. Preliminary Apparatus

Work on the apparatus was begun with a special set of tuning forks of the frequencies 150, 200, 250, 300, 350, 400, 450, 500. These were mounted on resonance boxes. They were to be kept vibrating by air impulses of the same frequency, blown into the resonance boxes of the forks. To secure air impulses of the proper frequency, a motor[2] was made whose magnetic fields were made and broken by an electrically driven tuning fork. This motor would run only when its rate of rotation synchronized with the vibration rate of the fork. Any tendency to run faster or slower would result in an acceleration or retardation such that it was forced into step with the fork. On the shaft of this motor was mounted a series of sirens with rectangular holes. Air under pressure was interrupted by these holes and led to the mouth of the resonator on the tuning fork. It was hoped that these air puffs would keep the tuning forks vibrating steadily and strongly.

The forks were not to furnish the tones to be used in experimenting, but were to act as generators of sinusoidal-electric currents which acted on a telephone receiver located in the piston of an adjustable resonator. On one of the prongs of these forks was fastened a coil of copper wire which moved inside of an annular coil on the opposite prong of the fork. When the forks were vibrating, these coils moved over and within each other in the same form of motion as that in which the fork prongs were moving. Since the prongs moved in a purely sinu-

[2] The motor was built on the same principle as the "phonic wheel" described by Lord Rayleigh. Theory of Sound, vol. I, p. 67. The motor was constructed by Max Kohl, Chemnitz, Germany.

soidal form of motion a constant electric current that was sent through one of the coils, would induce an alternating current having a sinusoidal form in the other coil. This alternating current then passed through the telephone resonator. It was found, however, that the tone was too weak and not pure.

The amplitude of the forks and the number of turns on the coils were not great enough to produce alternating currents which were strong enough to cause a strong tone in the telephone resonator. The vibrations of the telephone diaphram were furthermore not of a single sinus form, as was demonstrated by the presence of overtones. The diaphram vibrated not only in the forced period of the alternating current generated by the forks but also in other periods, due probably to the manner in which the metal and internal stresses were distributed over the disk and to the hysterisis effects of the magnet. At the time, it was thought that the difficulty was merely one of securing stronger electric currents. The air puffs did not seem to set the forks into vibration as strongly as was thought necessary to get the best results from the coils on the prongs of the forks.

It was then decided to drive the forks electrically. They could not be driven in the ordinary manner of electrically driven forks, because it was desirable to control their phase. To do this it is necessary that the moving parts that make the interruptions should be the same for all the forks. When the forks were being driven by the air puffs, this object was achieved by the common shaft upon which the sirens were mounted. It was decided to use a similar principle in producing the electrical interruptions which were now to drive the forks. Instead of having a number of seperate disks, a large disk of one-fourth inch copper and sixteen inches in diameter, was made. This disk had nine rows of holes of 10, 20, 30, 40, 50, 60, 70, 80, 90 holes to the row. These holes were filled with hard rubber plugs and the whole face of the disk ground to a plane surface. A series of bronze contact springs placed over the rows of holes opened and closed an electric circuit as the plugs and copper alternately passed under the contact points.

When the disk was driven at the rate of five revolutions per second, the various circles produced interrupted currents of the frequencies 50, 100, 150, 200, 250, 300, 350, 400, 450 per second. By sending these interruptions through the magnets of tuning forks of corresponding vibration rates, these forks would be set in vibration. The advantage of this method was that the amplitude of the forks could be controlled by varying the amount of current passing through the fork magnets. In this way it was hoped that the amplitude of the generating forks could be made great enough to give alternating currents of sufficient strength to secure a strong tone in the telephone resonator. The phase in which the different forks were vibrating could be controlled by shifting the contact brushes by variable sectors.

Great difficulty was encountered in the use of the type of synchronizing motor being used. It was found difficult to adjust the driving current so that the motor would run continuously. Slight variations in the current, variation in the friction from temperature changes or irregularities in the lubrication, were enough to throw it out of step with the regulating fork. All the indications seemed to be that this type of motor was too weak to drive the copper disk properly, the area of which was so great that air friction could be expected to have considerable retarding effect. However, even under favorable conditions of driving, the fork generators were too weak to give strong tones in the telephone resonator. Even during those rare occasions when the motor ran the disk with a regularity and smoothness beyond all criticism, the tones were too weak.

Instead of seeing that the difficulty was in the telephone principle we thought it was due to the fact that the alternating currents which were produced by the generating forks were too weak. We then took a large heavy 150 fork and made a new generating fork which was wound with much finer wire and consequently a larger number of turns. The magnet which drove the fork was also very efficient, giving an amplitude to the fork prongs as high as 6 mm. This was greater than we had ever secured before and much greater than we could hope to secure with the higher forks. Now there should have been

no question about the efficiency of the generating fork. We were able to send very strong currents through the inducing coils, but all we got out of the telephone resonator was a beautiful tone as long as the intensity was very low, but as the current was increased the tone became a loud snarl. At this point we should have realized that the difficulty was with the telephone resonator—but the good tones which we secured at low intensities prevented our seeing that a device which gives a pure weak tone need not necessarily give a pure strong tone. Again the blame was equally distributed between the generating forks and the motor.

We thought that the differences in potential were not great enough in the generating coils during one complete cycle of the fork. This difference in potential depends upon the amplitude of the fork; the greater the amplitude, the greater the difference in potential. The amplitude of the experimental fork we were using was, however, so much greater than we could use in the actual experiment on tone intensities, that we decided to use some other principle of getting a greater difference in potential. Accordingly we gave up the fork generator idea and began to develop the microphone principle.

Cylindrical resonators were made for four or five of the forks, which had at their bottoms a carbon telephone disphram placed against carbon granules. When the vibrating tuning fork was held to the mouth of the resonator, the air vibrations within the resonators transmitted their energy to the diaphram and set it into forced vibration. These vibrations changed the electrical resistance between the carbon granules and changed a constant current which was passing, into a varying current. This was then sent through the telephone resonator. Again it was found that the tones in the telephone resonator were too weak and not pure. For the lower intensities the system worked well, but for high intensities the tone became impure and scratchy. Toward the end we used currents which were so strong that the carbon disks and granules became so hot that the paraffin with which they were fastened, began to melt. But increasing the current did not increase the tone intensity to an appreciable extent.

The telephone idea was finally given up after many changes and modifications because a tone which was pure and strong enough to suit our requirements, was not secured.

The next step was to connect the prongs of the forks with diaphragms at the back of resonators.[3] The back of the resonator was made of a mica diaphragm. One end of a light wooden rod was attached to the diaphragm with sealing wax and the other end was attached to one of the prongs of the fork. This gave pure strong tones but they could not be started and stopped quickly. Overtones due to the mica disk appeared when the tones were very strong, but the results were more promising than anything that had been achieved thus far. It was decided to go ahead and devise a method by which the tones could be started and stopped quickly.

The Victor Talking Machine Company of Camden, N. J., very kindly sent us the sound transmitting parts of one of their talking machines. The needle of the sound box was allowed to rest on a piece of wood which had been attached to the prong of the tuning fork. The fork was kept vibrating continually and the tone was started and stopped by raising and lowering the needle on to the piece of wood. For low intensities the tone was good, but at the instant of dropping the needle on the fork a fearful racket was generated. The weight of the needle and the sound box also dampened the vibrations of the fork to such an extent that the tone became very weak and unsteady.

While these experiments with the source of sound were being conducted, the system for driving the forks was being perfected. The original synchronous motor being found too weak, work on a more powerful motor of the same type was started. While at work on this motor, the Leeds & Northrup Co., of Philadelphia, placed upon the market a constant speed device which seemed more promising.[4] What follows is a description of the apparatus finally used.

[3] This principle has been used successfully by A. G. Webster in his experiments on tone intensity standards.

[4] We did not buy the complete Leeds & Northrup apparatus but only the converter, rheostat and transformer because we did not think that the regulating fork as they had it mounted would give us the constancy of angular

2. Final Apparatus

The essential parts of the Leeds & Northrup constant speed motor are a regulating tuning fork and a rotary converter which is driven from the direct current side. The alternating current which is generated is treated by the regulating fork in the following manner: The fork is equipped with a second contact point (different from the one which serves the driving of the fork) which opens and closes the alternating current circuit of the converter, with a frequency corresponding to its own period.

The nature of the alternating current is such that it fluctuates in its intensity from zero to either the negative or positive maximum twice during every cycle of the alternating current coils. That is, if the alternating current is of the 60 cycle type, in every second there are 60 instants at which the current strength is at its positive maximum and 60 instants at which it is at its negative maximum. This principle is made use of in the form of a variable load to control the speed of the converter.[5]

The advantage of this system lies primarily in the fact that it furnishes considerable power and is not so limited as that of the type of motor which we used at first, where the current driving the motor must pass through the vibrating contact point, producing a big spark; whereas in this type, only the *regulating load* current sparks, the current *driving* the motor being continuous.

When the load used is in the form of lights, these furnish a visual index of the converter action and a means of regulating the driving current, so that the system will operate efficiently. The operator of the system soon learns to interpret the character of the lights and the noises which are made by the apparatus. It should be noted whether the converter is rotating in the

velocity within each revolution which is necessary to drive tuning forks by our method of interrupter disks. Such disks with their contact springs require considerable power and the regulating load is therefore relatively great. The Leeds & Northrup regulating fork has a double contact on metal which we also tried (see page 23) but found unsuited because slight adjustments changed the period of the regulating fork enough to make frequent retuning of the tone forks necessary.

[5] Further details are given under X of Details for Apparatus.

proper direction for getting the best contact conditions for the direct current carbons. If it is necessary to change the direction of the converter as received from the manufacturer, this is readily done by exchanging the terminals of the two lower direct current carbons.

3. Details of Apparatus Parts

A. Batteries

The laboratory is supplied with direct current from the power house at 110 volts and it was at first thought that this would be steady enough in its voltage to run the rotary converter without installing storage batteries. It was found, however, that the changes in voltage due to the turning on and off of light clusters and machinery on the campus, made the current too irregular to work satisfactorily. While the voltage is in general kept up to 110 volts at the power house by suitable regulating devices, yet the apparatus used in this experiment is considerably more sensitive and responds more promptly to changes than the devices used at the generating plant. At times during the day and especially late at night after the offices and halls on the campus are closed, the power house current becomes steady enough to run the entire apparatus.

While the batteries are expensive to install and require some skill in keeping them properly charged, the steady character of the current justifies the expense.

After the batteries had been set up they were used to run the converter only. The regulating fork and tone forks were driven from the power house line. However, double-throw switches were installed at numerous points so that any part of the system could be operated on either power house or battery service. This was of considerable advantage at first since it was easy to determine whether any trouble which developed was due to the character of the current or to the faults in the mechanical construction. It was found that flexibility, as represented by adjustable rheostats and numerous switches, was a great help in locating difficulties and unifying the operation of the system.

To secure the required voltage and capacity from the bat-

teries, 60 chloride accumulator cells, type C T, plates 5 x 5 inches, were bought from the Electric Storage Battery Company of Philadelphia. These were set up as shown in fig. 1. When fully charged and connected in series, they delivered a current of about 120 volts, 3 to 4 amperes, for about two hours. Since the power house current is only 105 volts, the 60 cells are not charged while connected in series but are divided into three units (I, II, III, fig. 1) of 20 cells each.

A

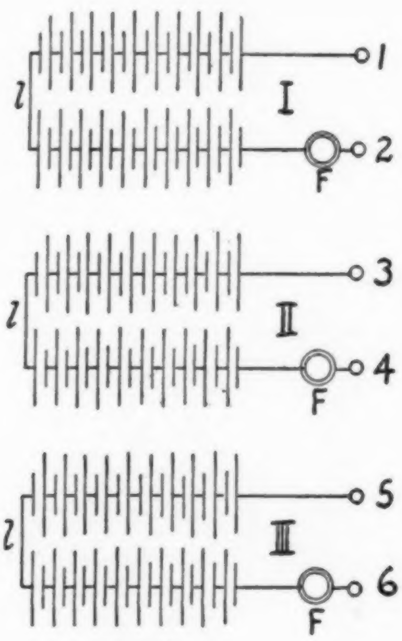


Fig. I

A. Batteries—showing manner of connection.

To save space and also allow for subsequent changes in the grouping, if this should prove desirable, each unit is divided into two sets of ten cells each, connected by a lead strip (*l*).

When batteries are charged in a form of connection different from the one in which they are discharged, there is considerable danger from short circuits being accidentally made when changing the connections from charge to discharge. To avoid seriously injuring the batteries in this way, a switch board (fig. 2) was made which simplified the manipulation of the batteries and avoided accidental damage. In fig. 1 the numbers

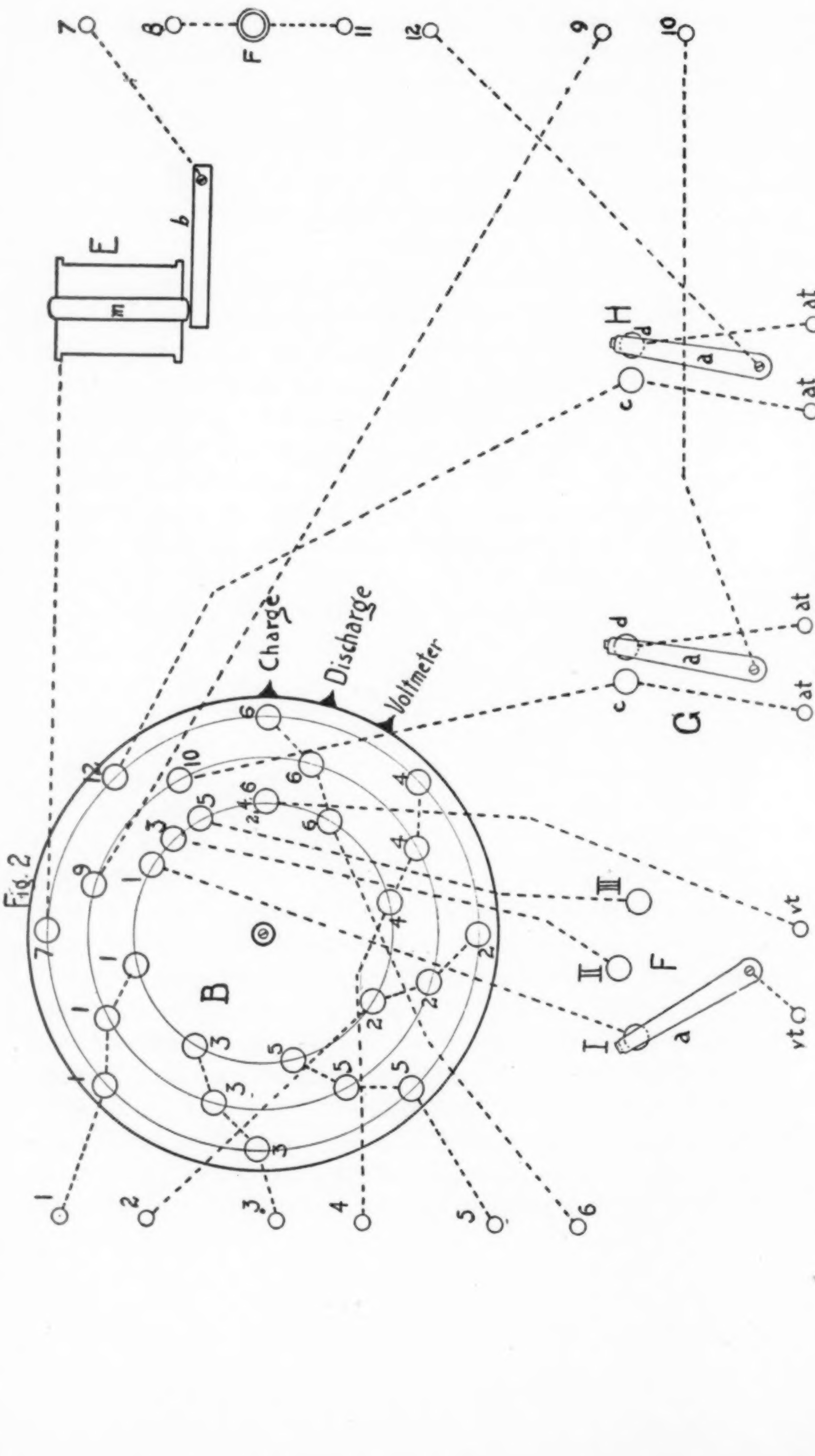


FIG. 2. BATTERY SWITCH CONNECTIONS.

from 1 to 6 are the terminals of the wires which come from the various end plates of the batteries and which end in the correspondingly numbered binding posts on fig. 2. The way in which these terminals are distributed over the switch board can be traced along the dotted lines leading from the terminals. All terminals having the same numbers are connected to the same wires. It is desirable and a saving of time if the testing of the voltage of the batteries and the measuring of the charge and discharge currents can be quickly and easily performed and it was for this purpose that the switch board was designed. The batteries, if properly handled, will last a long time but where it is necessary to make frequent changes of the connections, short circuits and accidents are bound to occur which will quickly injure the batteries unless such accidents are forestalled by automatic devices.

To simplify the battery end of the apparatus, the devices shown by drawings B, E, F, G, H, fig. 2, and C, D, fig. 3, were added. Their use and manner of construction will be explained under the proper headings.

B. Fig. 2. Switch board for making Battery connections.

This drawing shows only the lower connections. Over B is placed the dial-like disk C in fig. 3. The circles inside of B represent the heads of copper belt rivets (r fig. 3, D) which are driven through the wood base of the switch board and fastened by the copper washer (e). The rivets are arranged in three circles divided into sectors of 15 degrees. The rivet heads are spaced in such a way that their centers pass through the radii of these sectors.

C. Fig. 3. Battery Switch Detail

This is the top dial which shifts over the connections indicated in B. It is made of wood, half-inch thick and fastened to B by the screw in the center. B and C are to be regarded as a number of switches combined in such a way that a single shift of C will make and break a whole series of connections. Thus when C is set at "Charge" the battery terminals will be connected to the power house line ready for charging; the automatic circuit breaker E will operate; and the switch H will make it

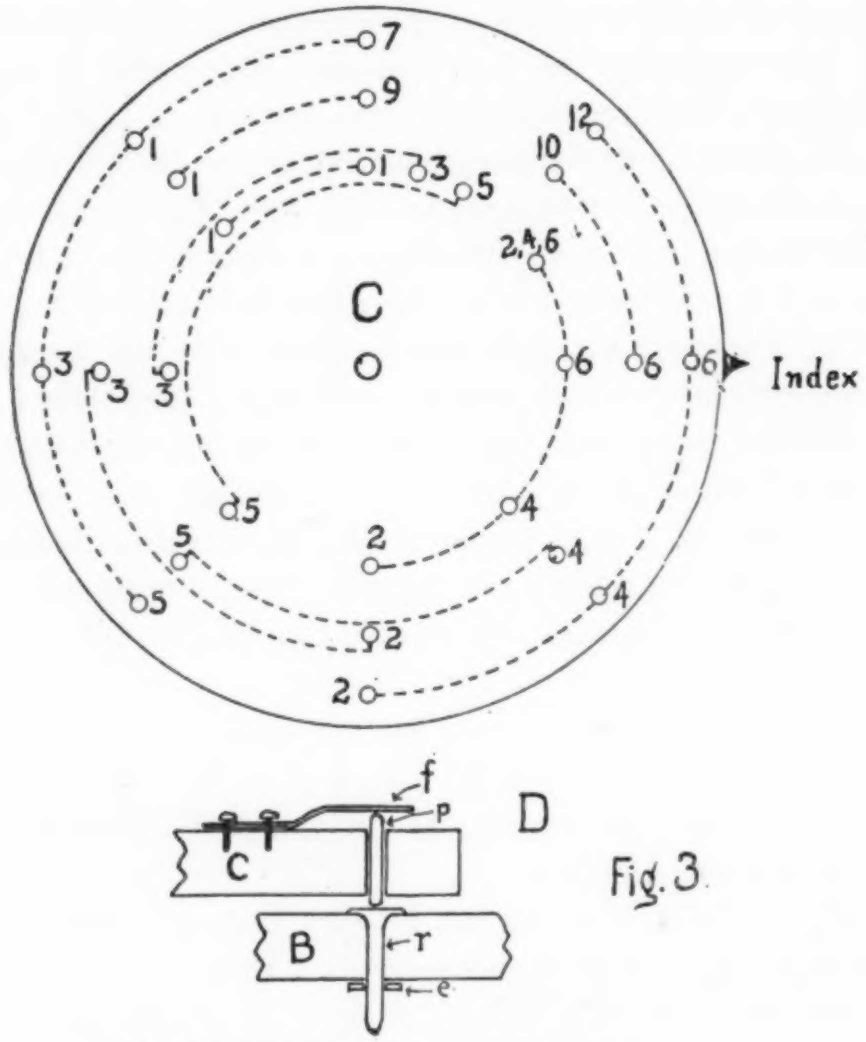


Fig. 3

C. Upper Dial of Battery Switch.
D. Form of connection between B and C.

possible to read the amount of current which is passing. When C is set at "Discharge" all the above connections are broken. The batteries are now connected in series instead of in parallel and the switch G, for reading the amperage of the discharging current, is thrown in.

When C is set at "Voltmeter" the switch F is thrown in so that the voltages of the battery units I, II, III, can be read successively. The details of the contact construction are drawn in D, fig. 3. Contact is made through the pins (p) one inch long cut from No. 8 copper wire. These pins pass loosely through holes drilled in C and are held in contact with the base B by bronze springs (f). The electrical connections indicated by the dotted lines on C are made through these springs. The springs

are flat ¼ x 1½ inches and cut from No. 29 sheet bronze, screwed into the wood by wood screws. When the pin (p) is not resting on the rivet (r) it runs on the wood base and is, of course, insulated from the set of connections which is in operation at the time.

To illustrate: When C is set at "Charge" the path of the current is from the terminal 7, of the power house line; through E to terminal rivet 7 on B; from here it passes through the pin 7 on C into the bronze contact spring; into wire indicated by dotted line to springs 1, 3, 5; into rivets 1, 3, 5, to battery terminals 1, 3, 5; through the batteries in parallel to battery terminals 2, 4, 6, on B; to rivets 2, 4, 6; through pins 2, 4, 6, on C; to pin 12 where the three branches are again united; to switch H; to rheostat between 11 and 12; and finally to the other power house terminal 8.

D. Fig. 3. Drawing showing the details of the connections between B and C

E. Fig. 2. Automatic Circuit Breaker

It often happens that the current supply from the power house is shut off temporarily while the batteries are being charged. The batteries will then discharge through the line and into any machinery or lamps which might have been turned on before the line current was shut off, if there is no device for disconnecting the batteries from the line. The current which is used to charge the batteries comes in through 7, passes through the iron bar (b) into the magnet core (m) and into the coil of the magnet. From here it passes to the switch board B and C. If for any reason there is a break in the charging current, (m) is no longer magnetic and the bar (b) is pulled away from the core (m) leaving the circuit open. This device is especially necessary if the batteries are charged at night and with the current on for only a part of the night.

F. Fig. 2. Battery Voltage Switch

This switch is for reading the voltages of the battery sets I, II, III. The voltages of the different sets are read independently. C is set to "Voltmeter" and the connections for reading the voltages are thus made ready. By moving arm (a) to I, the

voltage may be read for the set of batteries I; arm to II, gives the voltage of set II, etc. The voltmeter is connected to the terminal (vt) and should read up to 50 volts. The voltmeter may be set up at any convenient point, or removed for making measurements elsewhere, without disturbing the system. The voltmeter is not shown in the drawing.

G. Fig. 2. Battery Amperage Switch

This switch is for reading the amperage of the discharge or battery current. It is arranged so that an ammeter (not shown) and connected to the terminals (a, t) can be thrown in or out without interrupting the current and without causing a spark. When the arm (a) is shifted to lie on (c) the current passes from (c) through (a) and then directly to 10. In this setting the ammeter is thrown out and may be removed by disconnecting at (a, t). This is of advantage when it is desirable to use the ammeter for other purposes. When arm (a) is shifted to (d) the current passes from (c) to (a, t) through the ammeter; then to (d); then to (a) and then to 10. By placing (c) and (d) so near together that when arm (a) is shifted from one position to the other, there is an instant during which the arm is in contact with both (c) and (d), no spark will result when shifting. The ammeter should read to at least five amperes. This switch operates when C is set at "discharge."

H. Fig. 2. Charging Amperage Switch

This switch is for reading amperage of charging current when connected to batteries. Its construction is practically the same as that of G, but operates only when C is set at "Charge."

J. Fig. 4. Double-throw Sliding Switch

When this switch is set as shown in the drawing, the power house current from 7 passes through the interrupter disks V to magnets of tone forks W, through resistance L and milliammeter M back to terminal 8 of the power house line. When set at (c) the power house current is shut off and the battery current from 9 to 10 passes over the same circuit.

K. Fig. 4. Double-throw Sliding Switch

This switch is of the same pattern as J except that it controls the current for the rotary converter R. When the switch is set

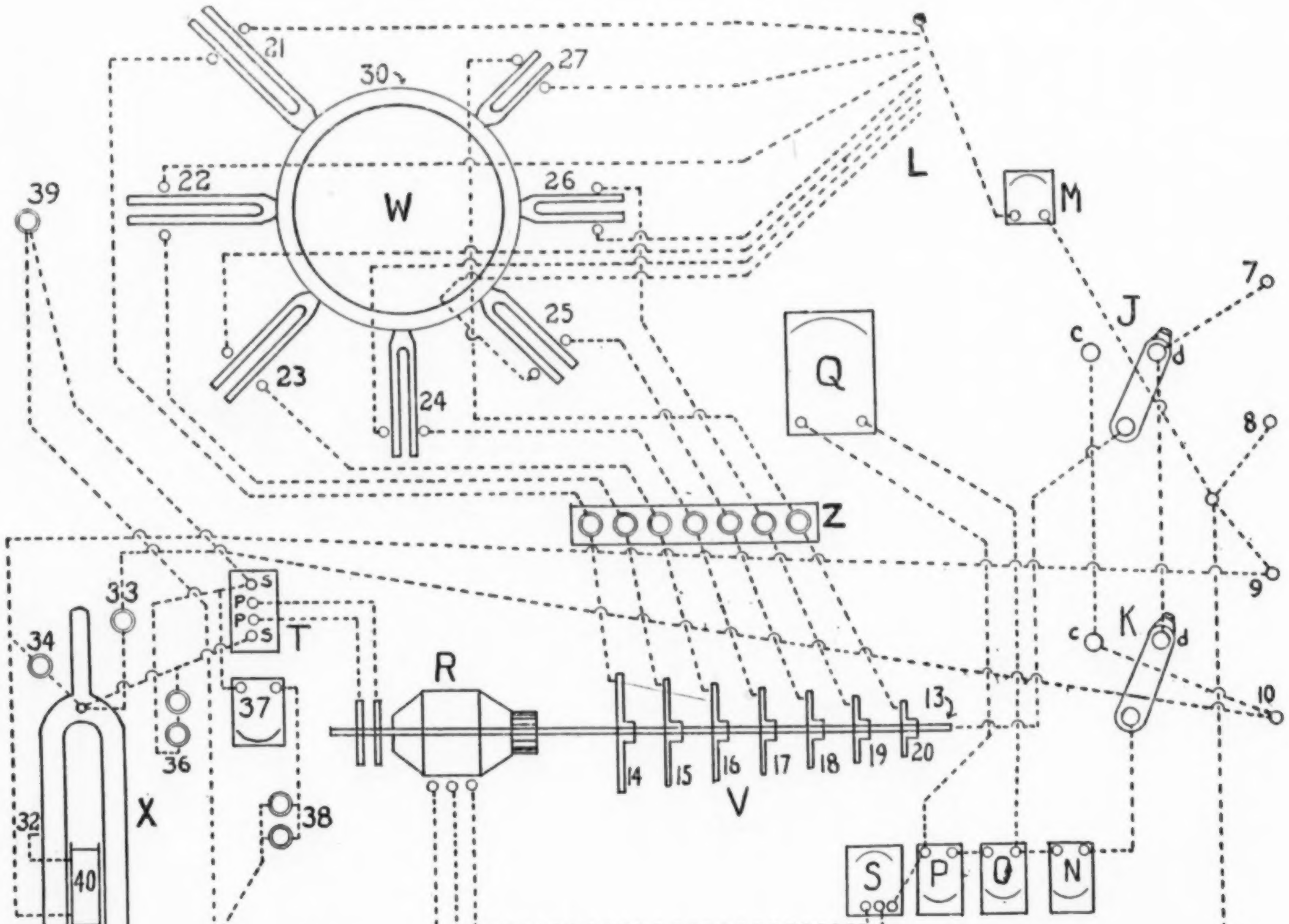


Fig. 4

Wiring Plan for Complete Apparatus.

at (d), the converter is driven by the power house current 7 and 8; when set at (c) it is driven by the batteries through 9 and 10.

L. Fig. 4. Special Resistance Board

It is desirable to have control of the current passing through the magnets of the tone forks W and preferably of each fork separately. However, a special resistance for each tone fork circuit requires more resistance boards than are usually available. A simple resistance board was made as follows: Between a board running around the base of the room and another board five feet from the floor, about 300 feet of No. 22 iron wire were zigzagged between nails about two inches apart. At the end of the wire coming from the fork, about an inch of tightly coiled brass spring was soldered. This coil serves instead of a binding post in that it can be pinched easily onto any of the nails over which the iron resistance wire is strung. To vary the resistance of the different forks it is only necessary to pinch the coiled springs on the wires coming from each fork, at different distances from the end of the resistance wire. By this method one resistance board will do for all the tone forks.

M. Fig. 4. Tone Fork Milliammeter

This is a Weston Milliammeter, Model 1, reading up to 300 milliamperes. Its use is primarily to indicate variations in the current passing through the magnets of the tone forks W. A resistance board placed between L and M makes it possible to regulate the resistance of the tone fork circuit as a whole so that any changes in the current strength may be compensated. The individual forks are regulated by the board L, but when running from the batteries the voltage gradually drops and it is desirable to regulate the system as a whole. This is done by keeping the milliammeter readings constant by the use of the resistance board between L and M. The Milliammeter is scaled to two milliamperes and even very slight fluctuations in the current strength are readily noticed. Slight variations up to 10 milliamperes make no appreciable difference in the amplitude of the tone forks, and the milliammeter makes it possible to make much finer adjustments than this.

N. Fig. 4. Resistance Board

Ward-Leonard Electric Company, Bronxville, N. Y., No. 443A Wire Dimmer for 12-30, 16 c. p., 110 volt, 50 watt lamps. This is only for coarse adjustment for the rotary converter.

O. Fig. 4. Resistance Board

This board serves the rotary converter R and contains 20 feet of No. 22 iron wire. There are 12 contact points and this means that twelve different changes in current strength can be secured. The type of connection is through copper rivets and a sheet brass arm which moves over the heads of the rivets. Sparking is avoided by placing the rivets so close together that the sliding contact arm is, for an instant, in contact with two rivets. The same principle is described in Switch G.

P. Fig. 4. Resistance Board

This board is of the same type as O and contains 24 feet of No. 18 iron wire distributed over 16 contacts.

Q. Fig. 4. Resistance Board

This board is of the same type as O and contains 100 feet of No. 20 iron wire distributed over 26 contacts. It is located in the experimental room and enables the operator to control the converter from the room in which the tone forks are located, without going into the converter room.

R. Fig. 4. Rotary Converter

Holtzer Cabot Electric Company, Boston, Mass., Type O. D., Size 1, 500 watt, volts 115/75, amperes 7.5, speed 1750 r. p. m., compound wound. This converter is driven by direct current and it generates alternating current which is used as a regulating load. The principle involved was described under Final Apparatus. The rotary converter serves as a motor driving the interrupter disks V through the direct connected shaft 13.

S. Fig. 4. Starting Box

Cutler-Hammer Manufacturing Company, Milwaukee, Wis., 1 h. p., 110/125 volts. This is a standard starting box arranged so that the converter is started gradually. It has an automatic circuit breaker which will break the circuit if for any reason the source of current supply is broken.

T. Fig. 4. Alternating Current Transformer

Holtzer Cabot Electric Company, Boston, Mass. Primary volts 75; secondary volts 220. Primary amperes 7.3; secondary amperes 2.3. Frequency 60. This transformer serves a double purpose. First, by having a higher voltage, the amperes of the alternating current are decreased and the heating effect of the spark made by the regulating fork X is reduced; Second, it prevents the direct current by which the regulating fork is driven from passing into the coils of the alternating current end of the converter; (s) and (p) refer to the secondary and primary coil terminals of the transformer.

V. Fig. 4. Interrupter Disks

These disks were made by Max Kohl, Chemnitz, Germany, from drawings furnished to him. They are made of brass into which have been inserted into round holes, hard rubber plugs which break a direct current which is passing from the disk into a contact spring, every time one of the rubber plugs passes beneath the spring. The number of interruptions will depend on the number of hard rubber plugs and the speed of the disk.

The surface upon which the contact spring slides is ground smooth and the diameters of the rubber plugs have been selected in such a way so that they are equal to the space between the plugs. When the contact spring is so set that it will make contact with the disk at the center of the plugs, the duration of the time during which current is passing through the magnets of the tone forks is approximately the same as when the circuit is open. These disks are mounted on the axle 13 which is driven by the converter R.

The springs through which electrical contact is made are of No. 30 sheet bronze, one-fourth inch wide and screwed to wood supports as shown in the photograph of the converter room.

Nos. 14, 15, 16, 17, 18, 19, 20, are the disks making 450, 400, 350, 300, 250, 200, 150, interruptions per second respectively, when the converter R is running at 1500 r. p. m. or 25 revolutions per second.

W. Fig. 4. Tone Fork Frame

This is located in the experimental room and consists of a

heavy cast iron ring 30, one and one-fourth inches thick, three and one-fourth inches wide and ten inches inside diameter. On this the tone forks 21, 22, 23, 24, 25, 26, 27, are mounted as shown in the photograph, by drilling holes into the ring and fastening the forks into these holes. The metal of the fork must not come in direct contact with the metal of the ring, or secondary tones and noises will result. To avoid this the feet of the forks are wrapped in felt sleeves and the washers and nuts by which the forks are fastened into the ring have felt washers placed between them and the metal.

The ring 30 is suspended from the ceiling by a rope and pulley which allows the frame to be lowered to a convenient height for making observations. This mode of mounting also permits the forks to vibrate with great amplitudes without giving a tone unless the resonators are placed near them. Above the forks the resonators are placed which produce the tones. The distance of the resonators from the forks can be read off on a millimeter scale and in this way the intensity of the tone is measured. The resonators are shown in the photograph of the Experimental Room by the numbers 21 to 27. They have been tuned to the same periods as their respective forks. The vibration rates of these forks are 150, 200, 250, 300, 350, 400, 450. The intermittent currents produced by the interrupter disks V pass through the magnets of these forks. When running properly the period of the interruptions coincides with that of the forks in the sense that the fork magnets attract the prongs of the tuning fork only at those instants when the prongs are moving toward the magnet. In this way the vibrations are maintained. The amplitude of these vibrations is controlled by the resistances L and Z.

X. Fig. 4. Regulating Fork

This is a fork made by Edelmann, Munich, having a period which can be varied from 36 to 55 vibrations per second by means of sliding weights. It is electrically driven through the contact 32. Its amplitude is controlled by the 4 c. p. carbon lamp 33. To reduce the spark at the gap 32, another 4 c. p. carbon lamp 34 is placed across the spark gap and coil. The

magnet 40 should be made as large and efficient as possible. Upon the constancy of this fork will depend the constancy of the whole system.

While for ordinary purposes the period of a fork can be considered to be independent of the amplitude, this is actually not the case with a magnetically driven fork. The variation of period is, of course, not very great but when all the tone forks are tuned to synchronize with the regulating fork, the slightest variation will influence the tone forks very materially. The variation in the regulating fork is multiplied when it reaches the tone forks. If the period of the regulating fork is changed .2 of a vibration per second from the regular period, this will amount to a whole vibration per second for the tone fork 250. This means that the electrical impulses which reach the tone fork 250 actually have the period 251 and that there is a complete reversal in the phase of the magnetic attraction of the fork prongs every second. This is sufficient to practically silence the fork 250.

The manner in which the regulating fork operates is as follows: the current generated by the alternating current end of the converter passes into the primary coils of the transformer T. The alternating current which is induced in the secondary coils passes into the fork and is interrupted at the mercury contact 35. The alternating current does not pass through the magnet which drives the fork.

During each revolution of the converter, the alternating current passes through two maxima and minima of current strength. If the fork closes the circuit when the phase of the alternating current is at its minimum strength, no load will be thrown on the converter. If the regulating fork closes the circuit at the instant when the alternating current phase is at its maximum, either negative or positive, a heavy load will be thrown on the converter which will retard its speed. If the driving current of the converter is so adjusted that it is just barely stronger than necessary to make the alternations of the converter coincide in period with the vibrations of the regulating fork, the alternations of the converter will tend to overtake the vibrations of the fork.

They cannot, however, advance very much because the magnitude of the alternating current load grows rapidly stronger as the phase of the alternations advances over the period of the fork. As a result the converter will "hunt" a point at which the load is just sufficient to keep the converter in step with the fork. The magnitude of the load which is used to regulate the speed of the converter, is controlled by the resistances, 36, 37, 38. A constant load 36 made of two 8 c. p. carbon lamps is introduced to dampen the spark formed at 35 and to reduce its heat and size. They also serve as visual indicators as to whether the carbons at the alternating current end of the converter are making continuous contact. The light should burn without a flicker even when the converter is not in step with the regulating fork. If the lights flicker jerkily this means that the carbons are not making good contact on the collector rings, and need to be sand-papered or adjusted.

As we are at present using the fork, it is regulating only half the number of times that it might regulate. If we had a contact point on each prong of the fork the vibrations of the fork would correspond to half cycles of the alternating current. With the fork equipped with two contact points and running in step with the alternating current cycles, if one contact comes at the positive maximum the other will come at the negative maximum. If one of the contacts is at zero the other will be at zero. As we have it now, the fork makes contact only at such parts of the alternating current cycle which are of the same sign. Notwithstanding this apparent loss in not utilizing all the regulating capacity of the fork, my experience has shown that it still works better with a single contact point in mercury than with two contact points on opposite sides of the same prong which then necessarily must act on solid metal.[6] This is probably due to the fact that the interruptions at the spark gap are more complete, thus bringing about a greater difference in potential. The alternating current load actually lasts longer than the instants during which

[6] I have not tried using a contact on each prong, both contacts dipping into mercury. Thus far it has not been found necessary, but with sounding forks of considerably higher frequency than those we have been using (say above 500 double vibrations) it may be advisable to do so.

the contact point is dipping into the mercury, due to the cohesion of the mercury to the contact point after contact is once made, and especially to the conductivity of the spark gap itself caused by the ionization of the gases and oil.

With a double contact on solid metal and the *maximal effective* distance of the contact points then reduced to one-half of the amplitude of the fork, the load may be prolonged to nearly half a cycle so that any change in the speed of the generator would no longer be accompanied by a change in load.

In the alternating current circuit which passes through the mercury contact at 35, there is a resistance board 37 made up of 120 feet of No. 27 German silver wire, distributed over 24 contacts. After the apparatus was running properly it was found that a constant resistance of two 16 c. p. carbon lamps at 38 was sufficient, and the resistance 37 was then taken out and used to regulate the general resistance of the tone forks between L and M.

A 4 c. p. carbon lamp 39 is placed in the experimental room and enables the experimenter to determine whether the converter is running properly. When this lamp fluctuates in brightness, the converter is running out of step with the regulating fork. When it burns brightly this means that the alternating current load is stronger than necessary. The resistance board Q which controls the driving current of the converter being located in the same room, it is easy to regulate the converter from the experimental room. A little practice is necessary to interpret the character of the glow in 39 properly. When the converter is running properly, the lamp 39 will glow dull red and fairly steady. If it goes out entirely this means that there is no regulating load on the converter. If the converter is, nevertheless, in synchronism this means that the driving current is just strong enough to drive the converter in step with the regulating fork. The light is really an index of the conditions at the spark gap 35.

Y. Fig. 5. Mercury Level Regulator

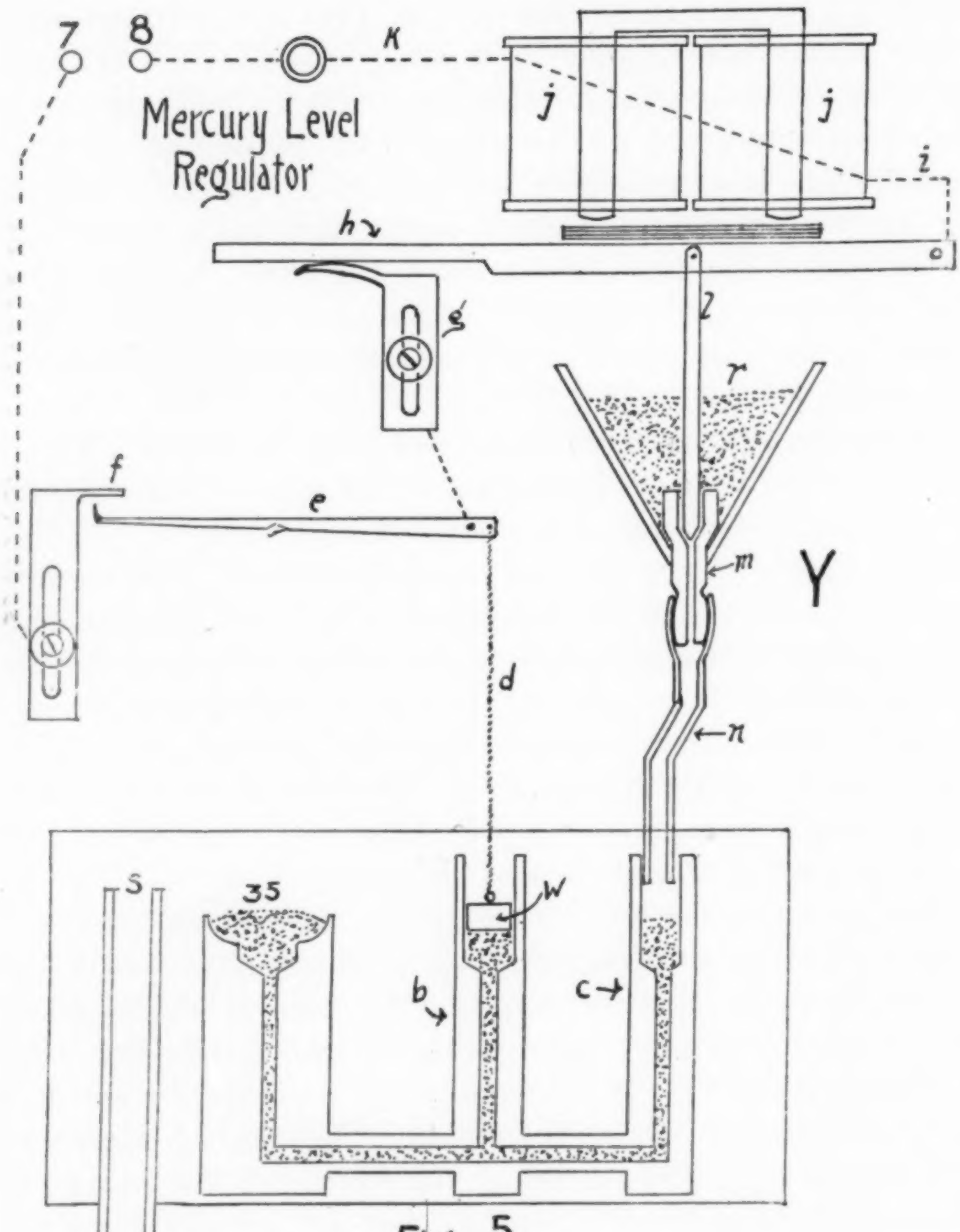
In order that the period of the regulating fork be kept constant from day to day, it is necessary that the extent to which its contact point dips into the mercury remain constant. This

would be a simple matter if the mercury were not splashed about, but to get the best control it is necessary that the point be blunt so that it will make and break suddenly. Such a point, however, churns up the mercury into an emulsion of coal oil and mercury. If this is not removed it gets between the contact point and the mercury surface and the electrical contact becomes irregular. If the surface of the exposed mercury is too large, the contact of the fork will set up stationary waves. In the nodes of these waves the mercury emulsion accumulates and gradually crowds around the contact point.

If the mercury surface is made so small that no stationary waves will form, the emulsion will be thrown off but the level of the mercury will change so rapidly that the period of the regulating fork may change sufficiently during an experimental series to require a retuning of the tone forks. A limited amount of the emulsion is a good thing because it reduces the splashing of the mercury, but unless the excess is constantly and automatically removed, contact difficulties and change in period of the regulating fork will appear.

The device drawn in figure 5 automatically takes care of the mercury level and the amount of the emulsion.

The cup into which the contact point of the fork dips is shown at 35. Its shape is as indicated,—a shallow cup into which the mercury is fed through the passage indicated by the stippling. At (b) and (c) are upright tubes communicating with each other and the mercury cup 35. The mercury is added to the tube (c) from the reservoir of mercury at (r). The tube (b) carries an iron weight (w) which floats on the mercury. Any change in the level of the mercury in the cup 35 will either raise or lower the weight (w). To this weight is attached a fine wire (d) which acts on the light bronze lever (e). This wire is insulated from (e) by making part of its length out of thread. When the mercury level at 35 is lowered the weight (w) sinks and thus raises the lever (e) until it makes contact with the plate (f). As soon as contact is made at (f) an electric current passes through (e) to (g), then to (h) and through (i) to the coils of the magnet (j) which raises (h) from the contact (g) and



METHOD BY WHICH THE LEVEL IN THE MERCURY CONTACT CUP WAS MAINTAINED CONSTANT.

breaks the circuit. When (h) drops back to (g) the cycle is repeated for as long a time as (e) is in contact with (f). To the arm (h) is pivoted the needle valve stem (l) which dips into the mercury reservoir and opens and closes the opening in (m). Every time (h) is raised, (l) is raised off the valve seat in (m)

and a drop of mercury escapes into the glass tube (n) and into the tube (c). When the mercury droplet reaches (c) it raises the level of (c) and also (b) and of cup 35. When the level of (b) is raised the weight (w) moves upward and in so doing the lever (e) is depressed and the connection between (e) and (f) broken. All of this happens much more quickly than can be described.

The sensitivity of the change in level will depend upon the relative lengths of the lever arms in (e). In the apparatus under discussion, the relation is about 1 to 20 and the break between (f) and (e) is rarely more than a millimeter. This represents a change in the level of the mercury of about .05 mm., a change so small that it cannot be detected in the load circuit.

After a drop of mercury has been added and the contact between (e) and (f) is broken, the excess of emulsion formed at 35 is gradually thrown over the rim of the cup and collects in the bottom of the tank where it lies until a considerable amount has collected. This emulsion has a large percentage of mercury in it which can be reclaimed by gradually drying the emulsion over a radiator or gentle source of heat.

All parts which come into contact with either the mercury or the emulsion are made of iron or glass as mercury forms an amalgam with most of the metals found in the laboratory.

The tank into which the mercury cup is placed is made of sheet iron and the tubes (b, c, 35) are kept in place by being imbedded in plaster of paris.

During operation the tank is filled with running coal oil to prevent heating and oxidation of the contact metals (iron and mercury) at 35. This oil drains off through the tube (s) into a collecting vessel. The top of the tube (s) is threaded and has a pipe coupling loosely screwed on so that the level at which the oil stands can be easily varied. The oil which drains off is rather dirty and has a considerable amount of free carbon in suspension. This is due to the electric spark at 35 which decomposes the coal oil. Before being used again the oil is run through the sand filter shown in the photograph, where these impurities are filtered out.

The plate (f) is made of bronze and is grooved so that it can be moved up and down for adjustment. The height of the mercury level is regulated at this plate before an experiment or series of experiments is begun. If the iron contact point does not dip into the mercury enough, the regulating load is too small. If the iron point dips in too much the load is so great that the variations in the load are too small. The mercury level is so adjusted by moving the plate up or down that when the motor is in synchronism with the regulating fork the filaments of the carbon lamps 38 glow a cherry red. After the level of (f) has been adjusted the device will maintain the mercury level at a constant distance from the iron point for many days or even weeks, until an appreciable amount of the iron point has been consumed by the spark.[7]

Z. Fig. 4. Lamp Resistance for Tone Forks

This is an ordinary lamp bank except that the lamps are not connected in parallel. There is one lamp socket for each fork and since this is only a rough adjustment 4 or 8 c. p. lamps will serve.

Tone Fork Magnets

If the magnets of the tone forks are properly made, they do not require a great deal of current to drive them at the desired amplitude. The current never exceeds one-fourth ampere and one-eighth ampere is usually sufficient. The magnets should be as wide as the spread of the forks will permit. The iron core should be heavy, at least one-half inch in diameter and the diameter of the coil should not be less than two inches. The wire used should be about No. 30 magnet wire, wound carefully so as not to get short circuits. Lamps alone are hardly a fine enough adjustment, for controlling the amplitudes of the forks. The finer adjustment is made at the rheostat L.

4. Method of Controlling Phase

Since the experimental work reported in this paper does not make especial use of the phase relations between the tones used, a

[7] The mercury cup in the photograph showing the Regulating Fork is only a preliminary cup which was used before the mercury level regulator had been completed.

complete description and mechanical drawings of this part of the sound intensity apparatus will be given when an experiment in which phase relations play a more important part will have been performed. However, a general outline of how we expected to secure and control any phase relations which we had anticipated might become an object for experimental investigation, may be of interest. The mechanical principles which we expected to use were the following.

1. The interrupter disks, when the contacts are once adjusted, give tones whose phase relations remain the same.

2. A moving contact which rotates or oscillates on the face of the interrupter disk.

3. Electro-magnetically controlled shutters which open and close the resonators so that only the particular phase relations which are to be studied are presented.

1. The interrupter disks referred to have been described under V of the Details of Apparatus Parts. In the experiment which follows, it was only necessary to establish the fact that all the forks were vibrating in the same phase. The contacts, as shown in the photograph of the converter room, can only be adjusted so as to increase or decrease the pressure on the disk. The phase was adjusted by loosening the set screw which held the disk onto the shaft and rotating the disk the required amount. To set all the forks in the same phase, the disks were so adjusted that all the resistance lights in series with the magnets of the tone forks (Lamp resistance Z, Fig. 4) lit up simultaneously when the interrupter shaft 13 was slowly moved by hand.

Where it is necessary to change the phase by a measurable amount a finer adjustment was contemplated. The bearing of the shaft 13 has a metal segment of an arc attached to the supports as shown in the photograph. Upon this segment a radial arm (also shown) may be clamped. The arm carries the contact spring and it may be regarded as one of the radii of the segment since they both have their virtual centers in the center of the interrupter shaft.

A micrometer screw arrangement clamps on to the segment and acts on the radial arm. The amount of phase displacement

of the contact point is derived from the angular displacement of the contact point. To calculate this, it is necessary to know the pitch of the micrometer screw, the length of the radius at which the screw acts on the radial arm and the number of contacts the disk makes in one complete revolution. Where it is desired to study the phase comparatively, the foregoing degree of adjustment is adequate, but where it is necessary to pass quickly from one phase adjustment to another, or where it is desirable to have one fork slowly changing its phase relative to another fork (floating phase) the manual method of phase displacement should be replaced by some mechanical method.

2. We contemplated doing this as follows: running parallel to the interrupter shaft we have an auxiliary shaft (not shown in photograph) which is driven by the interrupter shaft through a worm (which appears in the photograph as the extreme end of the shaft) and worm-wheel and bevel gears. It rotates at one hundredth the rate of the interrupter shaft. The auxiliary shaft carries an arbor pulley into which may be fastened sprocket wheels of various diameters. These sprocket wheels may be turned of wood with short nails driven into the periphery to act as sprockets for the links of a light driving chain.

A similar arbor pulley to which is fastened a radial arm and contact point, rotates around the interrupter shaft. By selecting the sprocket wheels of the proper diameters, the rotating contact may be made to furnish interruptions for a tone which differs by only a slight fraction of a vibration from the tone which is derived from the disk when the contact is fixed.

Where it is desirable to have only a partial phase displacement an eccentric is attached to the auxiliary shaft and this is connected to the radial arm carrying the contact which will now no longer rotate completely around the disk, but will oscillate back and forth between whatever angular limits the conditions demand. This may be used to study the critical points in a sound wave[8] (inflection points, relative maxima and minima of compound waves, etc.).

[8] The credit for the recognition of the need of sound experiments with controlled phase is Dr. Meyer's who has long been interested in determining experimentally whether we hear all that a Fourier analysis of a compound sound wave reveals, or whether we hear more, or what it does not reveal.

3. In order to make it possible to present the tones for observation when they are at exactly the phase relations desired, an electro-magnetic control of the resonator shutters was contemplated. This control was to originate from contacts suitably disposed on the auxiliary shaft. In this connection it may be well to draw attention to the fact that the auxiliary shaft is well adapted to chronoscopic functions by which the tones may be presented in any order. As already indicated the ratio of the revolutions between the interrupter shaft and the auxiliary shaft is as 1 : 100. The interrupter shaft rotates at the rate of 25 revolutions per second which gives the auxiliary shaft one revolution in four seconds.

By means of toothed wheels whose teeth are spaced to produce the required duration and alternation of the intervals, the times at which the various shutters of the resonators are opened and closed may be compounded into almost any kind of a series. Another advantage lies in the fact that the timing device is always in synchronism with the sound producing system.

II. EXPERIMENTS ON THE RELATIVE INTENSITY OF SUCCESSIVE, SIMULTANEOUS, ASCENDING AND DESCENDING TONES

What has preceded seems to deal with the physical principles of constant rotation and of tone production rather than with the psychological properties of tones. However, in psychology as in the other sciences the time has passed when it is possible to perform fruitful experiments on new problems with apparatus that was designed for other problems and that is now listed in the catalogs of dealers in psychological apparatus.

When the apparatus had been developed to the point at which it seemed profitable to begin the psychological experiments for which it had been designed, it was decided to begin with the simplest of tone intensity problems. This seemed to be the influence of the method of presentation upon the intensity relations between tones. At the close of the experiment the "simplicity" was decidedly less simple than it appeared to be at the beginning.

The reason why it was necessary to restrict the experiment to the *relative* intensity instead of working with absolute intensities and then from these deriving the relative values, was mainly due to the fact that no absolute standard which could be used was available. The Bureau of Standards at Washington does not furnish a tone of unit intensity which may be used as a standard. Professor A. G. Webster has defined a standard of tone intensity but to calibrate the intensities used in this experiment in terms of this standard would require an interferometer and a degree of technical skill in the manipulation, which would require months to develop. A simpler device is needed. The writer hopes, in the near future, to design an electrically driven fork which may be used as a standard for tone intensities which will be suitable for psychological laboratories and adapted to the needs of psychologists rather than the needs of the physicists. The situation in audition at the present time is similar to the situation which prevailed in vision before photometric

measurements had attained the perfection and simplicity which they now possess. Some kind of a standard of tone intensity must be devised. At first, as in vision, this will be some individual's standard but as interest in the subject develops, more fundamental standards will be developed.

1. Historical Setting

The references in the literature to tone intensity are mainly restricted to simple experiments where loud, medium and weak represent the nearest approach toward intensity control.

Such experiments as have been made are rather simple and were performed not to investigate the intensity relations between tones so much as to illustrate some phase of the writer's main thesis, be this in music or some of the other attributes of tones. For this reason no exhaustive attempt will be made, in this paper, to collect the scattered references to tone intensity. Such a task is a problem in itself and one for which the library facilities must be wider than those which are now available to the writer.

The facts which have impressed the writer most in his search through the literature can best be described by a quotation from Lord Rayleigh.[1] "In default of decisive experiments (on tone intensity) we must endeavor to balance the a priori probabilities of the case." Again, "What is most wanted at the present time is a better reckoning of the itensities of the various tones dealt with and observed."

Helmholtz[2] introduces the problem of tone intensity by pointing out that the intensity of a tone increases and diminishes with the amplitude of the oscillations of the sounding body. While numerous references are made to tone intensities throughout his extensive treatise, he did not perform experiments in which the intensities of tones was the cardinal consideration.

Seebeck[3] concluded that when a musical tone was compounded of several simple tones, part of the intensity of the upper constituents went to increase the intensity of the prime tone with

[1] Theory of Sound, vol. II, pp. 461, 469.
[2] Sensations of Tone. Transl. by A. J. Ellis. Second Engl. Edition, p. 10.
[3] Poggendorfs Annalen der Physik. Vol. 60.

which it fused so that at most a small remnant excited in the ear the sensations of an upper partial tone.

Stumpf[4] describes an experiment originally reported by Ohm.[5] When a tone and its octave are simultaneously bowed on a violin and the lower tone is suddenly dropped out, the remaining high tone seems to become stronger, and when the higher tone is dropped out the lower tone becomes noticeably weaker. Seebeck in commenting on the same experiment concludes from this that: tones when present even in considerable intensity can scarcely be heard as soon as the lower harmonic tone is added, but they do add to the intensity of the lower harmonic.

The experiments reported in this paper support Seebeck's law but with the relatively pure tones which were used, the effect is not nearly so pronounced as intimated by Ohm and Seebeck.

2. Statement of the Problem

Since no report on extended experiments in sound intensity is known to the writer, and since all theoretical interpretation of auditory phenomena must eventually consider the intensity relations between sounds, it was thought best to begin with the simple phenomena of tone presentation.

At the present time an experiment in vision which disregarded the facts of adaptation would not be attempted. We know now that the colors and brightnesses which we *shall* see, will depend largely upon the other colors and brightnesses that we *are now* seeing or *have just* seen. By this it is not implied that auditory reactions exhibit adaptation phenomena of the same character as that of vision. We simply know nothing about it. It is, however, important that we should know what to expect when tones are presented in different ways.

Of the various ways in which tones may be presented, four will be made the subject of this experiment.

1. Successive, or alternate tones.
2. Simultaneous, or tones sounding together.
3. Ascending, or varying from weak to strong.
4. Descending, or varying from strong to weak.

[4] Tonpsychologie. Vol. 1, p. 241.
[5] Poggendorfs Ann. d. Physik. Vol. 47.

From these four methods of presenting tones, four experimental series may be made up as follows:

1. Successive Ascending.
2. Successive Descending.
3. Simultaneous Ascending.
4. Simultaneous Descending.

In investigating the intensity relations presented in this way, it was decided to use the method of Supra-liminal Increments. This method requires a great deal of time and the results cannot be represented so easily nor so clearly as by the method of Right and Wrong cases. However, to use the latter method effectively it is necessary to predict the probable limits within which the phenomena to be investigated will occur. The method of Supraliminal Increments, thus in this sense is a necessary preliminary step. For this reason it was used in these experiments. To verify, by the method of Right and Wrong cases, the results of this experiment, is the logically following step in the experimental program.

3. Method of Experimentation and Observation

The tones throughout this experiment are produced by resonators hung over vibrating tuning forks. A guide on which the resonator runs, makes it possible to easily vary the distance between it and the prongs of the fork. A shutter covered with felt runs with the resonator. The shutter moves in a lateral direction and opens and closes the mouth of the resonator, thus starting and stopping the tone. The tone fork vibrates continuously, but being mounted on a rigid frame which is suspended from the ceiling by a rope, it cannot set into vibration any considerable surface of air and as a consequence it remains inaudible at the distance it is placed from the observer.

The resonators are counter-balanced so they will remain at whatever position they are placed. Each resonator may, however, be connected with a little crank in the arm of the chair in which the observer sits, enabling the observer himself to change the position.[6]

[6] The details may be traced out in the photographs showing the Tone Fork Frame and the Experimental Room.

When resonators are used as a source of sound, the tones seem to be purer than the tones secured from the forks when they are mounted on their own resonance boxes, and they are much purer than when the fork vibrations are conducted to the ears by means of tubes. The intensity of the resonator tone is somewhat illusory in that it seems weak when compared with ordinary sounds such as walking, talking, moving about, which are constantly occurring near class rooms. But when attention is directed to the resonator tone it can easily be discriminated out of a complex of sounds which seem to have a much greater intensity.

The two observers in this experiment were the writer (Obs. A.) and his wife (Obs. B.). Obs. A has worked with tones for a number of years, especially under the conditions found in psychological laboratories. Obs. B. has had some training in the laboratory and in general psychology, and considerable training in music.

It was hoped that a greater number of observers might have been used, but it was necessary to conduct the experiments at night and until the mercury level regulator had been perfected so many interruptions occurred, and series had to be repeated so often that the writer did not feel free to ask other observers to sacrifice their evenings for about a month. Furthermore, making intensity judgments requires a considerable amount of preliminary practice before they become constant enough to use in an experiment such as the one being conducted. Mrs. Weiss and the writer alternated as experimenter and observer. After a short time Mrs. Weiss was able to control the apparatus quite as well as myself.

The writer wishes to state here specifically what has been implied in other places, namely, that this set of experiments is preliminary in character to a more extensive program of sound intensity investigation. When laws are to be merely verified and the probable limits are quite well known, extensive experiments with many observers are necessary, but for problems dealing with the fundamental attributes, intensive rather than extensive experimentation is of greater value at first.

In this experiment the four tones 150, 200, 250, 300, were used. Each of the tones was presented in ten intensities, which ranged from a weak which could be heard easily when sounding alone, to a strong which was, however, not so loud as to be annoying. When a tuning fork tone is very strong it has a sort of "boom" to it which is distracting in intensity judgments. The ten intensities used can be described best by saying that the greatest and weakest intensities were well within the limits of the intensities to which we ordinarily attend. The loudest tone was not particularly loud, nor the weakest tone particularly weak. Between these limits were interpolated eight other intensities, making ten in all.

These intensities were measured on a millimeter scale placed so as to indicate the distance of the mouth of the resonator from the tuning fork prongs. The resonator was so placed that a line passing through the center of the mouth would pass midway between the prongs of the fork, at right angles to the axis of the fork.

In a preliminary series on the limens of intensities, it was found that equal steps on the millimeter scale do not represent equal differences in intensity. This was, of course, expected since the energy of a vibrating system is with approximation inversely proportional to the square of the distance. The scale between the limiting intensities was not divided into eight equal parts, but into eight steps derived from squaring a constant value. Thus, it was decided to take the strongest tone with the 150 resonator at about 15 mm. from the fork; the weakest intensity at about 75 mm. It was necessary to have a series made up of more than ten steps because equal intensities for the different forks are not found at equal distances. In other words when the resonator of fork 150 was at 50 mm. it did not give a tone of the same intensity as when the resonator of fork 300 was at 50 mm. It was desirable that the series be supra-liminal but yet close enough together so that all the intensities between the limiting intensities were represented. Finally the base of the series was chosen as .60. By squaring multiples of .60 a series of logarithmic steps result as follows: .36, 1.44, 3.24, 5.76, 9.00

12.96, etc. After dropping the decimal places the steps decided upon become 6, 9, 13, 18, 23, 29, 36, 44, 52, 61, 71, 81, on the millimeter scale. Of this series any ten adjacent steps will be equal to any other ten adjacent steps.

To convert the intensities of one fork into those of any other fork it is necessary to adjust them subjectively until they seem to be of equal intensity and then select that set of ten steps for each fork which groups, in the same order, around the points of the two millimeter scales found to be equal. It was thought at first that it would be simpler to set the resonators at equal intensities and then adjust the millimeter scales so that the readings on both would be the same. This would mean, however, that the readings did not mean distance of the resonator from the fork.

At this stage of the experiment it was not possible to maintain the intensity of any given fork constant for many days at a time and shifting the millimeter scales from day to day would introduce a group of variable quantities whose correction would be much more difficult than the conversion of the millimeter, to a tone intensity scale. As a matter of fact the ten steps, 13 to 81, were suitable for all the forks except 150 for which the ten steps were 6 to 61. These steps were, of course, arbitrarily chosen at the beginning of the experiment, but the final results shown in table XI show that they were satisfactory.

The method of making the judgments is that of "Selbsteinstellung." The observer sits under the sound frame W in the chair (Ch O) as shown in the Experimental Room photograph. The forks are 24 inches overhead and out of sight. The experimenter sits in the chair (Ch E). He changes the position of the resonator of the constant tone whenever a series has been completed and manipulates the shutters on the resonators. The tripod table (Tr) is used for recording the data. The resonator of the variable fork is adjusetd by the observer by turning the crank (Cr) located in the arm of the chair (Ch O).

It was decided at first to use a head rest and only one ear, but the results were less satisfactory and more variable than when the head is free to move, even though the effect of sound inter-

ference by reflected waves was thus a much more disturbing factor. By allowing the head free the *average* conditions were maintained more constant. Unless the head is clamped very rigidly and always exactly in the same position, greater variations result than when free to move. Fatigue and distracted attention also set in more quickly.

The combinations of the tones were twelve in all: 150-200; 200-150; 150-250; 250-150; etc., as shown in the tables. Each combination of two tones was given twice; once with the lower tone at constant intensity, and then again with the higher tone constant. The preliminary work on the intensity scale had given the observers sufficient practice to enable them to make the judgments easily. Considerable difficulty had been anticipated in making the judgments but this difficulty proved to be only temporary. Toward the end of the experiment, even when the tones were an octave apart the experimenter who was recording the results frequently marveled at the constancy of the judgments.

Secondary criteria such as the number of turns made with the crank, were eliminated by frequently altering the length of the cord. The judgments were made in the order, successive-ascending, successive-descending, simultaneous-ascending, simultaneous-descending, until the 40 judgments for each intensity had been made. Each of these four judgments requires a different adjustment and to use secondary criteria, it would be necessary to remember the kinesthetic conditions of the fourth preceding judgment.

The record sheet was in the form of the following table which represents a typical series for Observer A.

Position of constant fork 300.	Position of variable fork 200. Successive		Simultaneous	
	Ascending	Descending	Ascending	Descending
81	84	74	84	75
81	89	88	86	80
81	88	86	101	94
81	95	86	95	85
81	83	82	98	85
81	86	80	91	80
81	85	83	95	81
81	85	82	90	80
81	83	78	92	76
81	90	84	83	83
Median	85	82	91	80

The table shows the results for the fork combination 300-200 for the weakest intensity (1) used. The readings are in millimeters. For the twelve fork combinations, with ten intensities for each combination and for two observers, the total number of tables was 240. Since each table contains 40 judgments or "Einstellungen" the total number of judgments which formed the basis for the conclusions of the experiment was 9600. To secure the median values, as shown in the last line of the table, the readings were arranged on graph paper in order of their magnitude and the value in the fifth place, counting from the lowest, was taken as the median. For example, the values of the successive-ascending series in the table when arranged according to magnitude are 83, 83, 84, 85, *85*, 86, 88, 89, 90, 95. The value in the fifth place is 85 and this is taken as the median.

When the series were compared as shown in tables I to VI the new median (not the average of the two medians) was taken. Thus considering the comparison between the successive-ascending and the simultaneous-ascending series, the twenty values of both these series, arranged in order of magnitude is as follows: 83, 83, 83, 84, 84, 85, 85, 86, 86, *88*, 89, 90, 90, 91, 92, 95, 95, 95, 98, 101. The value found in the tenth position was taken as the median of both series. This value is 88. It happens that the median of both series combined is the same as the average of the two medians taken separately, but this need not be the case. The median of the series taken together was selected because it seemed more likely that this is the value which would have been secured had the two series been presented at random.

By taking the values in the fifth and tenth positions the true median is not found. In a series made up of ten trials the median would be found between the values of the fifth and sixth places, depending on the frequency of the adjacent values. This was considered an unnecessary refinement since all of the series were to be treated in the same way and the comparisons were relative, not absolute.

As already stated, the figures in the table represent millimeters, and in order to convert these millimeters into intensities it is necessary to multiply the derived values from the table by

a constant which is different for different distances on the scale. Thus the difference in millimeters between the medians of the successive-ascending and the successive-descending series is 85 — 82 = 3 millimeters. A difference of 3 millimeters when the resonator is at 85 does not produce as great a difference in intensity as a difference of 3 millimeters when the resonator is at 13. In order to correct for this and to convert the differences in millimeters into differences in intensity, each difference in millimeters was multiplied by a constant which depended upon the region on the millimeter scale in which the difference was located.

These constants were determined by taking the reciprocal value of the differences in millimeters between the successive steps. The steps decided upon were at 6, 9, 13, 18, 23, 29, 36, 44, 52, 61, 71, 81, on the millimeter scale. The differences between successive steps are 3, 4, 5, 5, 6, 7, 8, 8, 9, 10, 10, millimeters. The reciprocals of these values are .333, .250, .200, .200, .166, .143, .125, .125, .111, .100, .100. A difference of three millimeters in the region of the scale point 81 would thus be a difference in intensity of 3 × .100 or .3 of an intensity step. A difference of three millimeters in the scale region 25 would make a difference of 3 × .166 or .498 of an intensity step.

In the data never more than two decimal places were retained and the principle according to which decimals were dropped was the usual one of selecting the nearest whole number. In case the decimal to be dropped was 5 the nearest even number was taken. Thus .425 became .42 and .435 became .44. The decimals in all of the tables were reduced in this way.

As an illustration of how these values may be interpreted we will take the value of the variability for all the judgments which was found to be 1.48 steps. This means that when the constant fork resonator was set, for instance at the intensity 6 or at the distance 44 mm., one-half of the intensity judgments of the comparison fork fell within 1.48 intensity steps or 1.48/2 steps on either side of the median. The value .74 is a plus and minus value. To calculate the limits within which one-half of the judgments of the comparison fork will be found when the constant

fork was set at 44 mm., it is necessary to divide .74 by the reciprocal value (.143) for this region of the scale. This gives the value 5.1 which now represents millimeters. Using this now as a plus or minus quantity for the scale region 44, we have 44 plus 5.1 and 44 minus 5.1 which roughly gives the values at 49 and 39. Thus 49 and 39 represent the limits on the scale of the comparison fork resonator within which one-half the intensity judgments were found, when the constant fork was set at 44, provided the scales of both forks were the same. If this is not the case, a correction must be made but this does not effect the principle.

The values in the tables which follow are in terms of the ten steps which were used in the experiment. A plus value means that the tone under consideration was made stronger, while a minus sign means that the tone was made weaker to the extent of the steps indicated by the digits. The values of the tables can be converted into percentages of the whole range of intensities used, by moving the decimal point one place to the left. Thus the .74 step which was found to be the measure of the variability for all the intensities is thus changed to .074 which means that one-half the judgments of intensity were found to lie within plus and minus .074 per cent of the total range of intensities. Expressed more concretely, if one tone is held at a constant intensity and another tone is adjusted to the same intensity a large number of times, it will be found that one-half the judgments will lie within .074 of the total range of conveniently obtainable intensities.

4. Results and Conclusions

The tables which follow are in the main self-explanatory. The series which are compared are indicated at the head of the table. The numbers 150, 200, 250, 300, indicate the vibration rates of the four tones used. The results for the various combinations of these tones are found where the vertical and horizontal columns intersect. The tones of the first column were always the ones kept at a constant intensity.

The values below the blank diagonal in the upper table represent the values when the higher tone was the constant tone, and

the values above the diagonal—when the lower was the constant tone. The weakest intensity is designated as 1 and the strongest as 10.

The conclusion which is given is only the most obvious one. Further discussion of the results is taken up later.

The (A) table is derived from the same data as that from which the upper table was derived.

All forks vibrated in the same phase.

SUCCESSIVE ASCENDING
COMPARED WITH
SUCCESSIVE DESCENDING

The table values indicate the intensity steps that were added to the intensity of the Ascending tone, to give the intensity of the Descending tone.

TABLE I

Ten intensities combined. 4800 judgments.

Variable Tones

Constant Tone	150 Obs. A	150 Obs. B	150 Av.	200 Obs. A	200 Obs. B	200 Av.	250 Obs. A	250 Obs. B	250 Av.	300 Obs. A	300 Obs. B	300 Av.
150				1.41	1.16	1.28	.76	.83	.80	1.12	.89	1.00
200	.99	.81	.90				.84	1.02	.93	.80	.81	.80
250	.85	.63	.74	.78	.70	.74				.78	.71	.75
300	.91	.77	.84	.88	.68	.78	.88	.52	.70			

When low tone is the constant tone, average is................ .93
When high tone is the constant tone, average is............... .78
Average for whole table is .... .86

Conclusion:

When compared SUCCESSIVELY with a tone of constant intensity, tones varying from strong to weak (DESCENDING) are made .86 step stronger (or heard .86 step weaker) than tones varying from weak to strong (ASCENDING).

TABLE IA

Ten intensities separate. All combinations taken together.

Intensities

Obs.	1	2	3	4	5	6	7	8	9	10
A	.96	1.00	.75	1.00	1.12	1.00	1.00	1.00	.50	.75
B	.64	.60	1.00	.91	1.12	1.00	.75	.86	.66	.75
Med.	.80	.89	.84	1.00	1.12	1.00	.75	.86	.50	.75

The extent in steps to which the conclusion holds for the separate intensities is indicated in the last line.

SIMULTANEOUS ASCENDING
COMPARED WITH
SIMULTANEOUS DESCENDING

The table values indicate the intensity steps that were added to the intensity of the Ascending tone, to give the intensity of the Descending tone.

TABLE II

Ten intensities combined. 4800 Judgments.

Variable Tones

Constant Tone	150 Obs. A	150 Obs. B	150 Av.	200 Obs. A	200 Obs. B	200 Av.	250 Obs. A	250 Obs. B	250 Av.	300 Obs. A	300 Obs. B	300 Av.
150				.70	1.09	.90	.96	.73	.84	.88	.83	.86
200	.37	.86	.62				1.14	1.56	1.35	1.03	1.02	1.02
250	.94	.67	.82	.81	.96	.88				.73	.55	.64
300	1.05	1.07	1.06	1.06	1.08	1.07	1.02	.73	.88			

When low tone is the constant tone, average is................ .94
When high tone is the constant tone, average is............... .89
Average for the whole table is............................. .92

Conclusion:

When compared SIMULTANEOUSLY with a tone of constant intensity, tones varying from strong to weak (DESCENDING) are made .92 step stronger (or heard .92 step weaker) than tones varying from weak to strong (ASCENDING).

TABLE IIA

Ten intensities separate. All combinations taken together.

Intensities

Obs.	1	2	3	4	5	6	7	8	9	10
A	1.00	1.20	.91	.87	.84	.84	1.33	.75	.75	1.00
B	.80	.80	.87	1.19	.87	1.00	.84	.75	1.36	1.00
Med.	.84	1.09	.89	.96	.84	.87	1.14	.75	1.00	1.00

The extent in steps to which the conclusion holds for the separate intensities is indicated in the last line.

SUCCESSIVE ASCENDING
COMPARED WITH
SIMULTANEOUS ASCENDING

The table values indicate the intensity steps that were (algebraically) added to the intensity of the Successive tone, to give the intensity of the Simultaneous tone.

TABLE III

Ten intensities combined. 4800 Judgments.

Variable Tones

Constant Tone	150 Obs. A	150 Obs. B	150 Av.	200 Obs. A	200 Obs. B	200 Av.	250 Obs. A	250 Obs. B	250 Av.	300 Obs. A	300 Obs. B	300 Av.
150				-1.46	-.03	-.75	-.91	-.70	-.80	-.80	-1.34	-1.07
200	-.10	-1.12	-.61				1.50	.50	1.00	-.81	-.42	-.62
250	.46	-1.15	-.84	-.40	-1.56	-.98				.23	-.49	-.13
300	.09	-1.51	-.71	-.11	-1.03	-.57	.21	-.55	-.17			

When low tone is the constant tone, average is................ -.40
When high tone is the constant tone, averageis............... -.65
Average for the whole table is............................... -.52

Conclusion:

When compared with a tone of constant intensity, SIMULTANEOUS tones varying from weak to strong (ASCENDING) are made .52 step weaker (or heard .52 step stronger) than SUCCESSIVE tones varying from weak to strong (ASCENDING).

TABLE IIIA

Ten intensities separate. All combinations taken together.

Intensities

Obs.	1	2	3	4	5	6	7	8	9	10
A	-.14	-.20	.10	.29	0	.25	0	0	0	-.50
B	-.40	-.33	-.29	-.56	-.25	-.43	-.67	-1.17	-1.50	-1.67
Med.	-.40	-.26	-.11	-.29	-.25	-.29	-.25	-.50	-1.00	-1.33

The extent in steps to which the conclusion holds for the separate intensities is indicated in the last line.

Successive Descending
compared with
Simultaneous Descending

The table values indicate the intensity steps that were (algebraically) added to the intensity of the Successive tone, to give the intensity of the Simultaneous tone.

Table IV

Ten intensities combined. 4800 Judgments.

Variable Tones

Constant Tone	150 Obs. A	150 Obs. B	150 Av.	200 Obs. A	200 Obs. B	200 Av.	250 Obs. A	250 Obs. B	250 Av.	300 Obs. A	300 Obs. B	300 Av.
150				–2.36	–.86	–1.61	–.66	–.73	–.70	–1.27	–1.28	–1.28
200	–.74	–.75	–.74				.85	1.05	.95	–.59	–.21	–.40
250	.50	–1.08	–.29	–.32	–1.32	–.82				.22	–.56	–.17
300	.32	–1.06	–.37	.02	–.50	–.24	.47	–.34	.06			

When low tone is the constant tone, average is .... –.70
When high tone is the constant tone, average is .... –.40
Average for the whole table is ....–55

Conclusion:

When compared with a tone of constant intensity, SIMULTANEOUS tones varying from strong to weak (DESCENDING) are made .55 step weaker (or heard .55 step stronger) than SUCCESSIVE tones varying from strong to weak (DESCENDING).

Table IVa

Ten intensities separate. All combinations taken together.

Intensities

Obs.	1	2	3	4	5	6	7	8	9	10
A	–.10	–.22	.12	0	–.17	–.25	0	–.50	0	0
B	–.33	–.16	.09	–.29	–.33	–.37	–1.00	–1.00	–.75	–1.00
Med.	–.11	–.22	.09	–.22	–.33	–.37	–.50	–1.00	–.50	–1.00

The extent in steps to which the conclusion holds for the separate intensities is indicated in the last line.

Ascending
compared with
Descending

(Simultaneous and Successive series taken together)

The table values indicate the intensity steps that were added to the intensity of the Ascending tone, to give the intensity of the Descending tone.

Table V

Ten intensities combined. 9600 Judgments.

Variable Tones

Constant Tone	150 Obs. A	150 Obs. B	150 Av.	200 Obs. A	200 Obs. B	200 Av.	250 Obs. A	250 Obs. B	250 Av.	300 Obs. A	300 Obs. B	300 Av.
150				1.02	1.10	1.06	.84	.83	.84	1.02	.50	.76
200	.68	.85	.76				.96	1.27	1.12	.86	.87	.86
250	.86	.67	.76	.86	.99	.92				.83	.78	.80
300	.92	.71	.82	.88	.68	.78	1.01	.69	.85			

When low tone is the constant tone, average is .... .91
When high tone is the constant tone, average is .... .82
Average for the whole table is .... .86

Conclusion:

When compared with a tone of constant intensity, in mixed simultaneous and successive order, DESCENDING tones are made .86 step stronger (or heard .86 step weaker) than ASCENDING tones.

TABLE VA

Ten intensities separate. All combinations taken together.

Intensities

Obs.	1	2	3	4	5	6	7	8	9	10
A	1.00	1.10	.80	1.00	1.00	1.00	1.00	.75	.75	1.00
B	.80	.82	.87	.89	.84	1.00	1.00	.84	.75	.50
Med.	1.00	.90	.84	1.00	.84	1.00	1.00	.75	.75	.75

The extent in steps to which the conclusion holds for the separate intensities is indicated in the last line.

SUCCESSIVE
COMPARED WITH
SIMULTANEOUS

(Ascending and Descending series taken together)

The table values indicate the intensity steps that were (algebraically) added to the intensity of the Successive tone, to give the intensity of the Simultaneous tone.

TABLE VI

Ten intensities combined. 9600 Judgments.

Variable Tones

Constant Tone	150 Obs. A	150 Obs. B	150 Av.	200 Obs. A	200 Obs. B	200 Av.	250 Obs. A	250 Obs. B	250 Av.	300 Obs. A	300 Obs. B	300 Av.
150				−1.70	−.20	−.45	−.71	−.46	−.58	−.85	−1.17	−1.01
200	−.31	−.98	−.64				1.84	.96	1.40	−.55	−.64	−.60
250	.62	−1.12	−.25	−.37	−1.46	−.92				.15	−.56	−.20
300	.27	−1.50	−.62	.06	−.73	−.34	.49	−.31	.09			

When low tone is the constant tone, average is.............. −.24
When high tone is the constant tone, average is.............. −.45
Average for the whole table is.............................. −.34

Conclusion:

When compared with a tone of constant intensity, in mixed ascending and descending order, SIMULTANEOUS tones are made .34 step weaker (or heard .34 step stronger) than SUCCESSIVE tones.

TABLE VIA

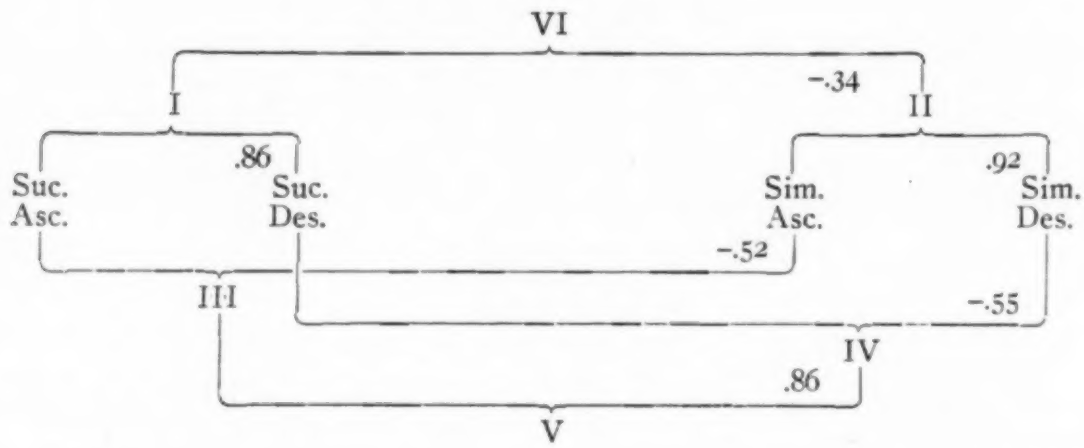
Ten intensities separate. All combinations taken together.

Intensities

Obs.	1	2	3	4	5	6	7	8	9	10
A	−.08	−.10	0	00	−.22	0	.25	.29	0	−.25
B	−.50	−.26	−.14	−.28	−.24	−.50	−.50	−1.25	−.75	−1.50
Med.	−.10	−.26	0	−.28	−.24	−.50	−.50	−.57	−.25	−.84

The extent in steps to which the conclusion for the separate intensities holds, is indicated in the last line.

5. Comparison and Discussion of Results



The above diagram will show more clearly how the tables and conclusions are related. It is to be remembered that the original data was in the form of four series. These four series form the starting points of the braces which connect those series which were used to make up the tables indicated by the Roman numerals. The numbers in the right arm of each brace are the extent in steps which the series nearest the number was made stronger (or heard weaker) if the value is positive, or made weaker (or heard stronger) if the value is negative, than the companion series. Thus, the —.52 in the right arm of the brace III means that the simultaneous-ascending tones were made .52 step weaker (or heard .52 step stronger) than the successive-ascending tones, when compared with a tone of constant intensity. The same principle is carried through for the other combinations.

From the diagram it also appears that the simultaneous tones were made weaker (or heard stronger) than the successive tones, and the descending tones are made stronger (or heard weaker) than the ascending tones.

It will be well to make clear just what this means. Consider as an illustration the comparison between simultaneous and successive tones of which the tone 200 is the constant and the tone 250 the variable. Assume that 200 is set at intensity 5 or at 36 mm. The tone 250 is started at silence by the observer and slowly made stronger while being *successively* compared with the intensity of 200. Suppose when they are equal that the scale

of 250 also reads 36 mm. This reading is recorded. Now 250 is again returned to silence and then gradually made stronger, but this time the adjustment is made while the tones are sounding *simultaneously*. In this case it is found that 250 is not made as strong as when the comparison was made successively. In other words, when given simultaneously 250 was reported equal *before* it actually reached the position at which it was stopped when it was compared successively. Briefly, 250 was left weaker when given simultaneously than when given successively.

Introducing a subjective term, we can say that 250 was "heard" as equal while objectively it was still weaker than it had been when reported equal successively. Advancing another step, when a tone is *made weaker* under a set of conditions (A) than it is under a set of conditions (B), when the instructions actually are to make the tones "equal" in intensity, we may say that the tone was "heard stronger" under the (A) conditions. This means that had the resonator actually been advanced to the position which it had in the (B) set, it would have been *judged stronger* than the constant tone.

From the foregoing it should be clear that the subjective characterization "heard" is derived from the *reaction*. This is the reason that it has been treated parenthetically in the tables and in the discussion. It is the reactions—the moving of the resonators more or less—which form the basis of this experiment. The subjective terms "heard stronger or weaker" are introduced for two reasons: 1. Many psychologists are interested in the subjective conditions; 2. The opposition between the relations "making stronger" and "hearing weaker" is likely to be overlooked. It is easy to conclude that because a tone was "made stronger" it is also "heard stronger" whereas a little reflection will show that the opposite is the case.

The type of the reactions which the observers made in the experiment with ascending and descending tones can be described by saying that the reactions did not go far enough. In tones varying from weak to strong, the observer left the tones too weak; in tones varying from strong to weak, they were left too strong. It is possible that the stimulus for stopping the reaction

is not only the intensity of the tone but also the amount of *change* in intensity which it has undergone. When the observer had changed the tone a certain amount, he gave the "equal" reaction, though with respect to intensity the reaction was premature. It must be remembered, however, that the amount of change in the intensities of the tones varied for the different steps. Thus the ascending tones were always started at silence. When working on intensity 1, the change between silence and intensity 1 is very little as compared with the change from silence to intensity 10. For the intermediate steps, of course, there were intermediate degrees of change.

Another fact which tends to reduce the effectiveness of the *amount of change* as a substitute for the reaction to the intensity only, was the fact that the ascending and descending series alternated. The amount of change in intensity when ascending is just the opposite of what it is in descending. It is only in the medium intensities that the amount of change is the same both for ascending and descending tones. This does not mean that the change in intensity is without effect, only it is not likely that it may be substituted for the reaction to the intensity. It seems to the writer that it is more correct to say that the judgment "equal" in ascending and descending tones is the result of both the (1) actual intensity of the tones and (2) the amount of change in intensity which the variable tone has undergone. These two factors interact in such a way that ascending tones are made weaker than descending tones.

The type of reaction characteristic of the judgment that was made when successive and simultaneous tones are compared, is of a different order than that of ascending and descending tones. When the intensity of successive-ascending tones is compared with that of simultaneous-ascending tones (Table III) the direction and magnitude of the change in intensity is the same for both series, in that they both start from silence and are brought to equality. We find, however, that the simultaneous tone is made about a half step weaker than the successive tone. This reaction seems to be conditioned only by the tone intensity.

Whether the stimulus which releases the "equal" reaction pre-

maturely (in the physical sense) is simply the tone intensity cannot be determined without further experimental analysis of the tone intensity reaction. Previous habits of tone perception most probably play a role. Do we have the habit of giving attention to the variable rather than to the constant tone? Do we give attention to the higher rather than to the lower tone? Do we give attention to the components of a compound tone differently when the difference of the vibration rates between them is great than when it is small? Do we attend differently to the intensity when the interval is consonant than when it is dissonant?

A scientific analysis of the tone intensity judgment or tone intensity reaction will make it necessary that these questions be answered not only affirmatively or negatively but quantitatively. As we approach the solution of some of these questions we can subject the various theories of audition to a much more searching and effective criticism than it is possible from mixed qualitative and a priori considerations.

Quite early in the experiment it was noted that there was a considerable difference between the averages of the observations in which the low tone was the constant tone and those in which the high tone was kept at constant intensity. This is so apparent in all of the tables that it seems improbable that it was due to some error in the control. In comparing the tones successively, each resonator was alternately opened and closed as often as was necessary to enable the observer to shift the variable resonator until the variable tone seemed equal in intensity to the constant tone. During this time each tone may have been sounded a dozen times and whether the high tone had been sounded first or the low tone first, would have been forgotten. Furthermore, no definite plan was followed as to which tone, variable or constant, higher or lower, was the starting tone. In the simultaneous tones both resonators were opened at the same time and left open until a judgment had been made.

From this it does not appear that the difference between the averages when the higher tone is constant or the lower tone constant, is due to any constant in the manner of presenting the tones. There is involved in this fact perhaps some habit of

auditory perception. So far as the sense organs in the ear or the character of the sound waves are concerned there should be no such difference in the averages. One thing which bears on this subject is the difference between the relative intensities of successive and simultaneous tones as revealed by tables III, IV, VI, in which it was found that the simultaneous variable tones are made weaker than the successive variable tones. This shows that when tones sound simultaneously they affect each other in a manner differently than when they sound successively. The question arises, do we approach the simultaneous tone conditions as the intervals between successive tones become shorter and shorter, or even as combinations which start as successive tones are left to overlap and become partly simultaneous? The observers noted frequently that the intensity judgments for successive tones were different from the intensity judgments of simultaneous tones. To illustrate, if the intensity of tone 150 is constant and 200 is made of the same intensity successively, then when both sound simultaneously 200 will be found to be too strong. It may be adjusted again to 150 and the judgment that 150 and 200 now sounding simultaneously are equally strong will be clear and unambiguous, but to say that the intensities of the simultaneous tones are the same as the intensities of the successive tones is quite a different matter.

To answer this question it is necessary that a third or standard tone be introduced according to the following plan. Take tones 150A and 150B and 200; equate 150A with 150B for intensity, successively; then adjust 200 until it is equal in intensity to 150B, successively; then treat 150B and 200 as a single tone and sound simultaneously, varying 150B until it is equal to 200. The difference between the readings of 150A and 150B will show the influence of the tone 200 on the intensity of 150B when given simultaneously.

It is in some such manner that the influence of one tone upon another, so far as the intensities are concerned, will need to be worked out, before it will be possible to explain why the averages of the tables seem to be influenced so much by whether the high or the low tone is the constant tone. This is the next problem

that the writer hopes to take up, but preliminary to this is the development of some simple absolute standard for tone intensity.

The individual differences between Obs. A and Obs. B have not been treated in this paper. All the tables will reveal the fact that they are of considerable magnitude but to try to explain these differences with the data of only two observers might lead to conclusions which would need to be materially modified with a greater number of observers. It would have been better, of course, to have started with a greater number of observers but for reasons indicated in another part of this paper it was not found practicable. Besides the results of this experiment will make it possible to attack the problem of individual differences in a much simpler way.

The smaller (A) tables which give the values for the ten intensities separately, show that the phenomena which are characteristic for each table are rather evenly distributed over the ten tone intensities.

The strengthening of the descending tone as shown by table IA occurs mainly with the medium intensities. The same thing is to be noted in IIA.

The weakening of the simultaneous tone as shown by table IIIA is least in the medium intensities, but in table IVA it is least with the lower intensities. It seems to be clear, however, that the weakening of the simultaneous tones is greatest at the higher intensities. This is perhaps only an extension of the same principle. If simultaneous tones are weakened, we should expect them to be weakened most where the intensity is greatest, because greater differences in intensity are possible where the tones are loud than where they are weak.

6. The Variability of Intensity Judgments

Tables VII to XI show the extent to which the judgments of intensity varied. The values of the tables are in intensity steps and represent the range over which half of the judgments were distributed. Thus the value 1.80 taken at random from the combination 150-200, table VII, means in this case that one half of the intensities were found within less than 2 intensity steps. This value may also be considered as a measure of the accuracy of the

judgments in that one-half the value indicates the deviation of these judgments above and below a given intensity. The way in which the variability value is derived is as follows.

To consider the variability for the combination successive-ascending and simultaneous-ascending for the intensity 1 (81 mm.) the values of which are given in the specimen table, page 39, and arranged in order of magnitude on page 40. In this series there are 20 judgments, the median value of which is 88. By taking the value in the fifth place 84 and the value in the sixteenth place 95, these limits will include slightly more than one-half of the judgments. The difference between these limits is 95 — 84 = 11 mm. which represents the limits within which the resonator moved for one-half the cases. In reducing the millimeters to intensities, the difference 11 is multiplied by the reciprocal .10 (page 41) which is the factor in the region of the scale 88 mm. This gives the value 1.10 which is the measure of variability.

VARIABILITY OF SUCCESSIVE TONES
(ASCENDING AND DESCENDING TAKEN TOGETHER.)

TABLE VII

Ten intensities combined. 4800 Judgments.

Constant Tone	150 Obs. A	150 Obs. B	150 Av.	200 Obs. A	200 Obs. B	200 Av.	250 Obs. A	250 Obs. B	250 Av.	300 Obs. A	300 Obs. B	300 Av.
150				1.94	1.65	1.80	1.52	1.76	1.64	1.78	1.31	1.54
200	1.45	1.20	1.32				1.70	1.65	1.68	1.40	1.47	1.44
250	1.35	1.10	1.28	1.46	1.34	1.40				1.62	1.32	1.47
300	1.33	1.24	1.38	1.06	1.25	1.16	1.57	1.16	1.36			

(Variable Tones: 150, 200, 250, 300)

When low tone is the constant tone, average is................ 1.60
When high tone is the constant tone, average is............... 1.32
Average for the whole table is................................ 1.46

VARIABILITY OF SIMULTANEOUS TONES
(ASCENDING AND DESCENDING TAKEN TOGETHER.)

TABLE VIII

Ten intensities combined. 4800 Judgments.

Constant Tone	150 Obs. A	150 Obs. B	150 Av.	200 Obs. A	200 Obs. B	200 Av.	250 Obs. A	250 Obs. B	250 Av.	300 Obs. A	300 Obs. B	300 Av.
150				1.42	1.96	1.70	1.49	1.79	1.64	1.64	1.35	1.50
200	1.15	1.28	1.22				1.88	2.19	2.04	1.75	1.71	1.73
250	1.27	1.35	1.31	1.35	1.46	1.40				2.08	1.36	1.72
300	1.77	1.45	1.61	1.48	1.52	1.50	1.65	1.31	1.48			

(Variable Tones: 150, 200, 250, 300)

When the low tone is the constant tone, the average is........ 1.72
When high tone is the constant tone, average is............ 1.42
Average of the whole table is.............................. 1.57

VARIABILITY OF ASCENDING TONES
(SUCCESSIVE AND SIMULTANEOUS TAKEN TOGETHER.)
TABLE IX

Ten intensities combined. 4800 Judgments.

	Variable Tones											
	150			200			250			300		
Constant Tone	Obs. A	Obs. B	Av.	Obs. A	Obs. B	Av.	Obs. A	Obs. B	Av.	Obs. A	Obs. B	Av.
150				1.70	1.47	1.58	1.44	1.96	1.70	1.54	1.64	1.59
200	1.42	1.29	1.36				2.38	1.67	2.02	1.57	1.52	1.54
250	.98	1.47	1.22	1.21	1.80	1.50				1.44	1.42	1.43
300	1.10	1.54	1.32	1.02	1.31	1.16	1.44	1.19	1.32			

When low tone is the constant tone, average is............... 1.64
When high tone is the constant tone, average is............... 1.31
Average for the whole table is............................... 1.48

VARIABILITY OF DESCENDING TONES
(SUCCESSIVE AND SIMULTANEOUS TAKEN TOGETHER.)
TABLE X

Ten intensities combined. 4800 Judgments.

	Variable Tones											
	150			200			250			300		
Constant Tone	Obs. A	Obs. B	Av.	Obs. A	Obs. B	Av.	Obs. A	Obs. B	Av.	Obs. A	Obs. B	Av.
150				2.44	1.45	1.94	1.58	2.04	1.81	1.96	1.76	1.86
200	1.15	1.53	1.34				2.66	1.99	2.32	1.50	1.69	1.60
250	1.24	1.17	1.20	1.40	1.68	1.54				1.50	1.32	1.41
300	1.34	1.29	1.32	.98	1.18	1.08	1.54	1.40	1.47			

When low tone is the constant tone, average is............... 1.82
When high tone is the constant tone, average is............. 1.32
Average for the whole table is............................... 1.57

VARIABILITY WITH RESPECT TO INTENSITIES
(SUCCESSIVE, SIMULTANEOUS, ASCENDING AND DESCENDING COMBINED)

TABLE XI

Ten intensities separate. 9600 Judgments. All combinations.

	Intensities									
Obs.	1	2	3	4	5	6	7	8	9	10
A	1.50	1.33	1.33	1.61	1.37	1.43	1.50	1.50	1.50	1.25
B	1.40	1.37	1.50	1.44	1.50	1.25	1.33	1.50	1.67	1.50
Med.	1.50	1.36	1.40	1.44	1.37	1.33	1.43	1.50	1.50	1.50

Average for the whole table is........................... 1.48

The tables show that successive tone intensities are less variable than simultaneous tone intensities, and ascending tone intensities less variable than descending tone intensities. Introspectively it seemed to the observers that the simultaneous judgments were the more accurate though the tables show the reverse. In the descending judgments the introspection agrees with the tables. However, the differences in the variability are not pronounced. It is rather remarkable that the judgments are so constant. This is a promising fact for future work on sound intensity. The average of *all* the tables is 1.48 steps. Half this

value .74 represents the deviation of half the judgments, above and below a hypothetical average intensity.

For example, if the constant tone is set at intensity 5 then one-half of the judgments in making a variable tone of equal intensity will be found to lie between the intensities 4.26 and 5.74. This value 1.48 also corresponds well with what was expected in planning the experiment, namely, that the difference between the intensity steps should be supra-liminal. Had they been subliminal, the value would have been greater than 2.00. Since we started with ten intensity steps and the deviation is plus and minus .74 we can say within the limits of the intensities actually used, there are 14 just noticeable differences in intensity.

By extending the intensities to very loud and very faint it seems conservative to suppose that at least 25 tone intensities could be discriminated.

The differences between the averages when the high tone is the constant tone and the low tone is the constant, are perhaps even more pronounced than for tables I to VI. When the high tone is the constant tone, the variability is considerably less. This is of importance for future experiments in tones as it tends to show that where the nature of the investigation permits it, comparisons should be made with the higher tone as the constant or standard tone, rather than the lower.

The variability for the separate intensities as shown by table XI is slightly less for the medium intensities. However, even the variability of the limits, 1.50 or plus or minus .75 show that the intensities are still considerably above the limen. The table also shows that the value .6 which was used as the base for the logarithmic series was well chosen.

According to this the limen for tone intensities should be found at squares of the multiples of .5 or less, when distance in millimeters of the mouth of the resonator from the prongs of a tuning fork is taken as a measure of the intensity.

7. Relation Between Variability and Difference in Vibration Rate

In table XII it is shown that the accuracy with which intensity judgments are made is not proportional to the difference in vibra-

tion rates. The intensities of two tones near each other in vibration rate are not necessarily judged more accurately than the intensities of two tones farther apart. The factors which are involved in making a judgment of intensity have not been isolated in these experiments and until they have been, intensity judgments will be of a mixed character in which both the tonality and vocality of the tones are involved.

It is because he is convinced of the complex character of the intensity judgment, that the writer has refrained from treating the individual differences between the two observers of this experiment until he has made experiments directed toward a further analysis of the tone intensity reaction.

At the beginning of the experiment it was supposed that the variability of the intensity judgments would be least when the difference between the vibration rates of the tones was least, but within the limits of the vibration differences within which this experimental work lies, it was found that the judgments were more accurate when the difference in vibration rates was 100. The following table gives the variability for the three vibration differences which were used.

TABLE XII

	Difference in Vibration Rates.		
	50	100	150
Variability	1.58	1.44	1.50

This shows that the variability was greatest when the difference in vibration rates was only 50, whereas at a difference in vibration of 100, the variability was least. Even at 150 the variability is not as great as at 50 but since there are only two combinations out of the twelve in which the difference was 150, reliable conclusions cannot be drawn. The significant thing is that the variability is so constant. The combinations of this investigation do not exceed an octave and it would be interesting to know whether the variability shows a correlation with octave relationships or not.

8. Relation Between Variability and Consonance

The preceding table leads to the idea that perhaps the variability is correlated with the dissonance or consonance of the in-

tervals which were used. Table XIII shows the variability with respect to the intervals.

TABLE XIII

Ratio	1:2	2:3	3:4	3:5	4:5	5:6
Name	Octave	Fifth	Fourth	Maj. VI	Maj. III	Min. III
Var.	1.56	1.60	1.53	1.47	1.73	1.46

From this table it cannot be concluded that the consonance of the interval is correlated with the variability. However, the data of this experiment gave only two combinations of forks for each interval, and the effect would need to be strong indeed had it appeared. From the impression which gradually developed during the course of the experiment it seems probable to the writer that both difference in vibration rates and the ratios of the intervals have an influence upon the judgments of the tone intensities. It is these facts mainly which led him to conclude that the intensity judgment in audition is really a mixed judgment. A tone may be judged as strong as another tone one moment, but presented again a few moments later, they will be judged of different intensity.

A complete analysis of the tone intensity reaction will need much more experimental data than is contained in these pages. But the outlook is promising for one who is able to meet the mechanical difficulties incident to the control of conditions.

9. Notes on Drawings and Photographs

Small circles about 1-16 inch diameter, represent binding posts or terminals. In drawing C fig. 3, they represent the kind of terminal shown in detail in D fig. 3.

The next sized circle, ⅛ inch diameter represent sliding contacts as in rheostats or starting boxes.

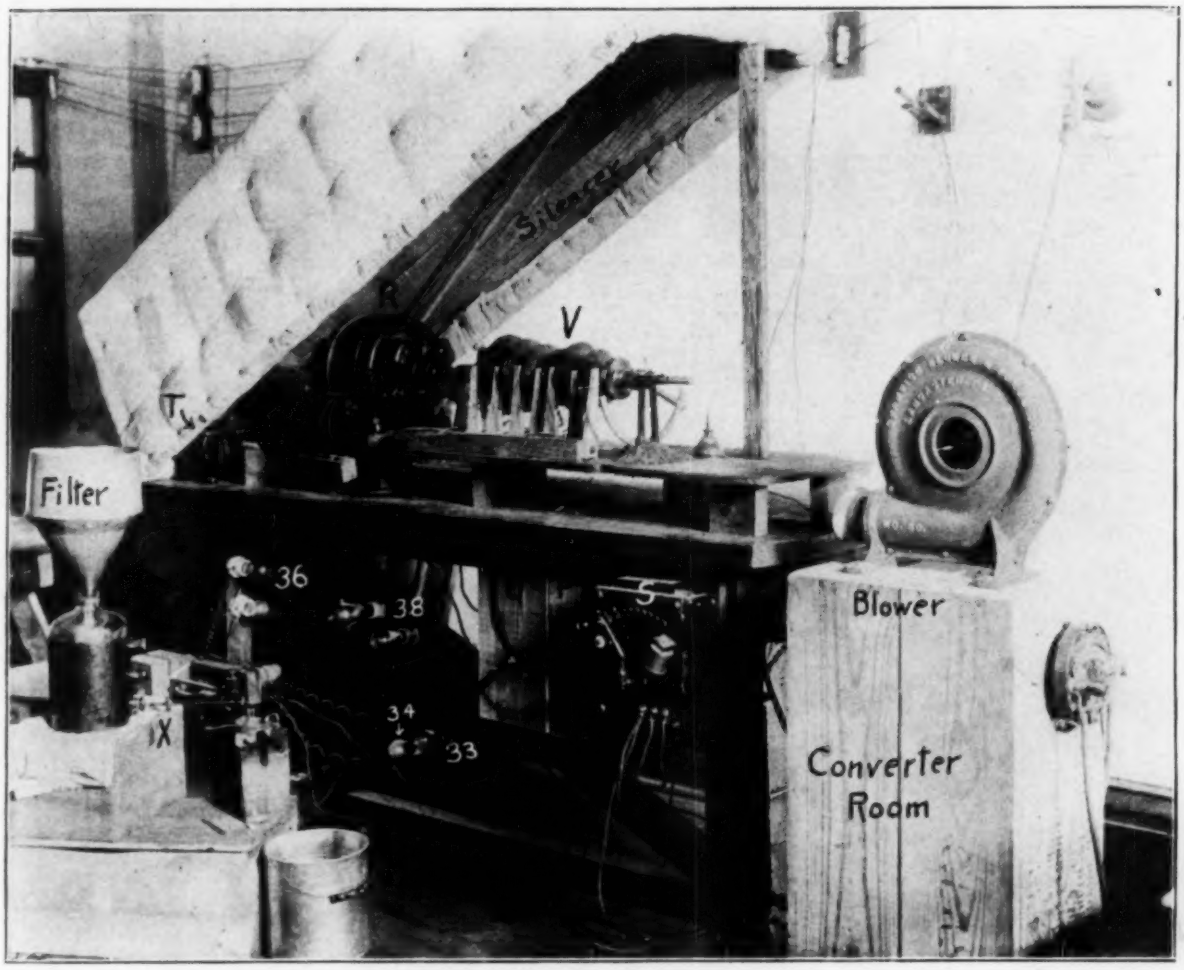
Double circles, the outer one of which is ⅛ inch diam. represent regular 110 volt lamp sockets. When an F is placed near the circles, this means that the socket is used as a fuse and carries a plug of about 5 amperes, 110 volts, capacity.

All terminals having the same numbers are connected to the same wires.

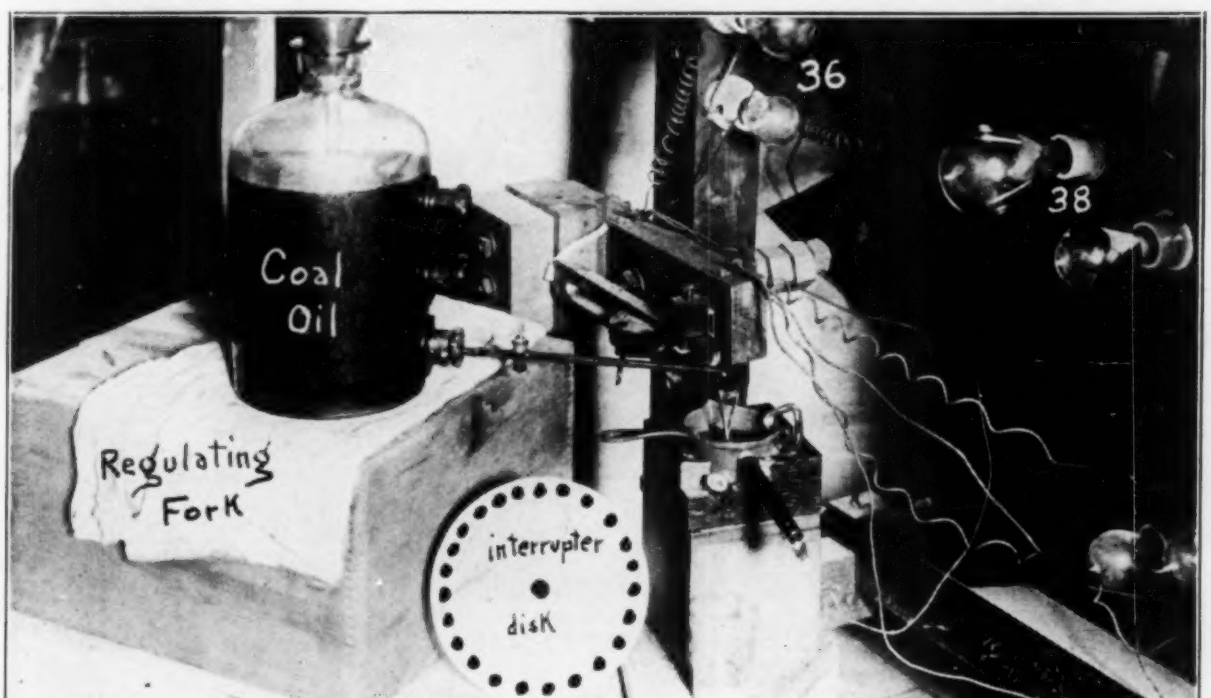
The numbers or letters on the photographs refer to similar numbers on the drawings or in the description.

The room in which the converter and regulating fork are located is separated from the experimental room by a large hall. They are not connected in any way except by the electrical wiring.

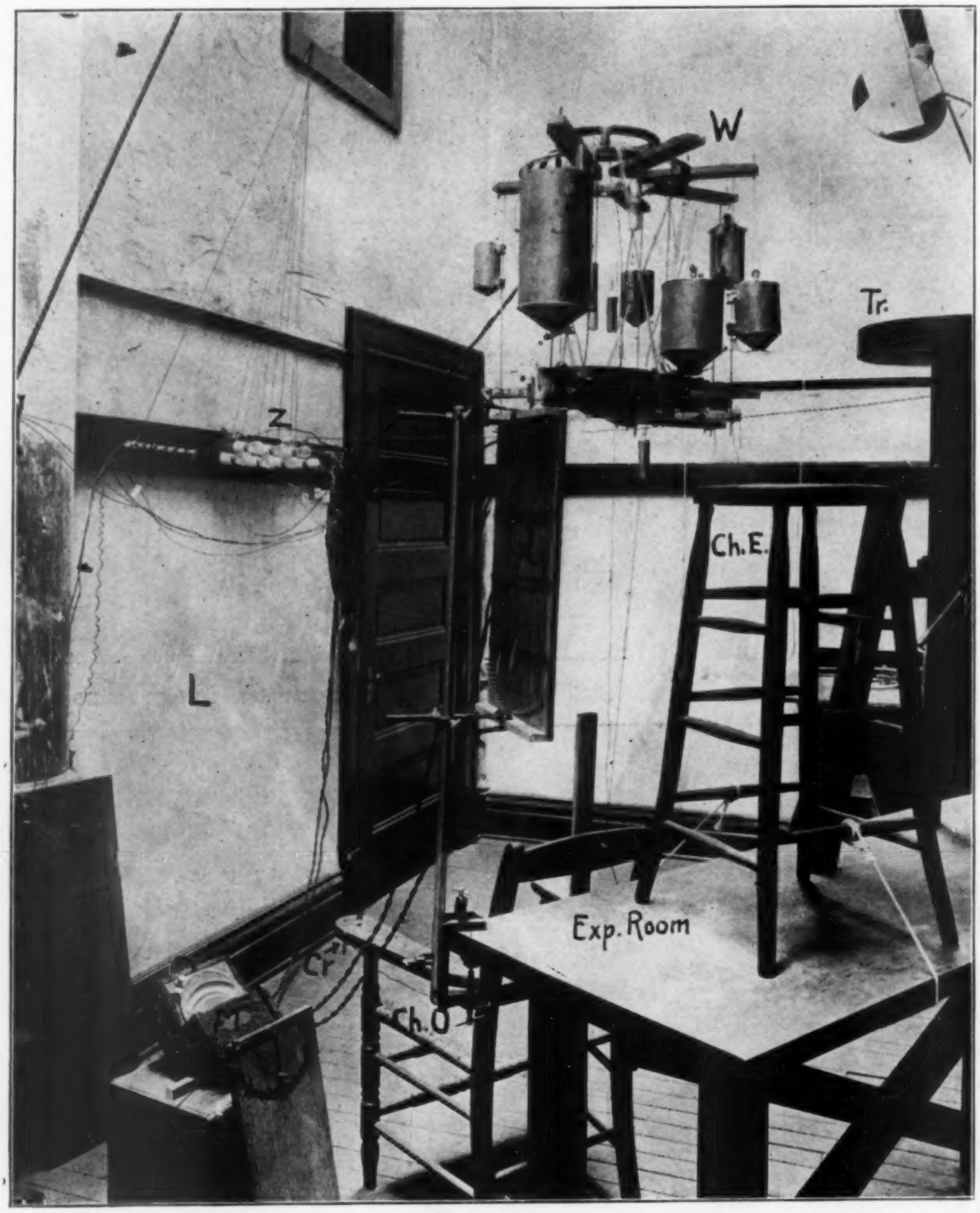
These two rooms might have been separated by a still greater distance and it would then not have been necessary to construct the silencing hood for the converter shown in the photograph. This hood drops down and encloses the converter when it is running, thus reducing the noise so that it cannot be heard in the experimental room when the two doors which seperate the rooms are closed. When the hood is down, the blower also shown in the photograph blows air into the silencing hood and against the converter to keep the latter from heating.



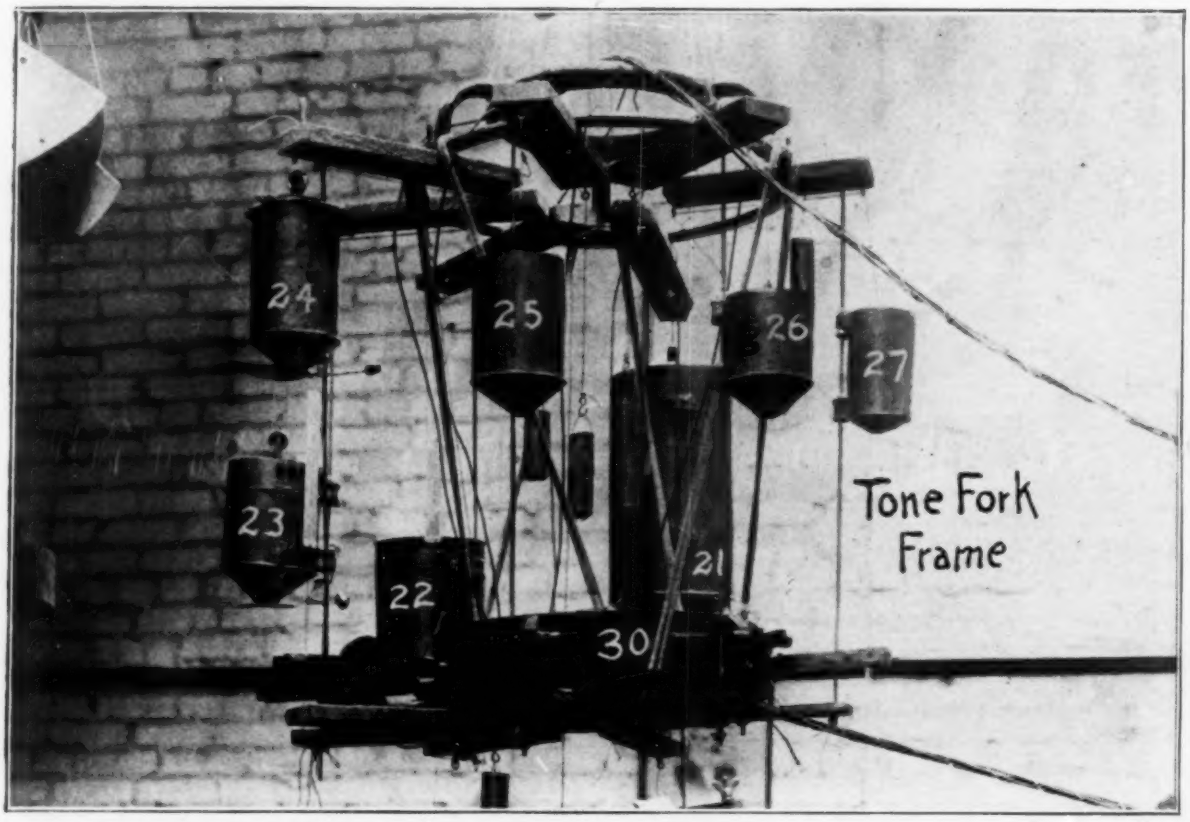
Photograph of Converter Room and apparatus for driving tone forks



Enlarged view of Regulating Fork.



PHOTOGRAPH OF EXPERIMENTAL ROOM IN WHICH THE TONES ARE PRODUCED.



ENLARGED VIEW OF TONE FORK FRAME SHOWING RESONATORS AND TUNING FORKS.